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SALIENT POINTS CONCERNING THE GLACIAL GEOLOGY OF NORTH GREENLAND.

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Possibility of continuous glaciation between Greenland and adjacent lands.—The study of the west coast of Greenland raised, but did not settle, the question of the possibility of continuous glaciation from a land mass, such as Greenland, over an intervening body of water, such as Baffin Bay and Davis Strait, to another land mass, such as the continent of North America. While the idea that the North American ice of the glacial epoch had its center in Greenland is no longer tenable, it does not appear that the possibility of such a thing has been doubted.

Even a cursory inspection of the west coast of Greenland seemed to show clearly that ice has not overridden the entire

coastal region of the island in recent times, and perhaps never. So far as could be judged from topography in passing, it did not even seem probable that ice from the main island ever crossed the narrow Waigat so as to become continuous with that on the island of Disco, although both the coast of the mainland in this latitude and the main portion of the Disco coast appear to have been glaciated. The topography of the coast bordering the Waigat is such as to suggest that the east coast of Disco has been glaciated by ice moving to the eastward from the interior of the island, while the opposite coast of Greenland appears to have been affected by ice moving toward the westward.

The plateau of Greenland often terminates abruptly near the coast, with a precipitous face 1500 to 3000 feet in height. Between this abrupt bluff and the water, there is usually no more than a narrow strip of low land, and often none. Along those parts of the coast where the ice-cap comes out to the edge of the plateau, it fails to reach the water for any considerable stretch. It is true that the ice, where it now reaches the edge of the abruptly terminated plateau, generally reaches it with a slight thickness only; but thick or thin, its edge breaks off and falls to the bottom of the cliff. Where the amount of ice breaking off and falling to the base of a cliff is great, it sometimes becomes re-united, and develops a small glacier. Such glaciers were seen both along the east side of Disco, and at various points on the coast of Greenland.

If the ice-cap on the upland were to advance more rapidly, or in greater mass, the amount of ice falling over the cliffs would be greater, and the glaciers formed at their bases would be correspondingly larger. It is conceivable that they might develop on such a scale as ultimately to become continuous with one another laterally. At the same time, by growth at their upper ends, they might become continuous with the ice-cap above. In this case the ice might move out from the interior over the coastal cliff without inflicting sufficient wear on the cliff face to greatly reduce its asperities, for the rough face would be to leeward. But it would not appear that such an ice-cap

on a plateau like that opposite the island of Disco could push out across a body of water like the Waigat, and overspread the island, without inflicting pronounced wear on the east bluff-face (stoss side) of that island. The freedom of the steep east side of Disco from such marks as the moving ice should have left, indicate that Greenland ice never surmounted it.

Further north in Whale Sound stands Herbert Island, distant but a few miles from the coast of Greenland to the south. For a considerable distance, the opposite coast of Greenland appears to have been glaciated, at some relatively recent time, by ice moving toward the coast; but the topography of the south face of Herbert Island gives no suggestion that the ice from the mainland ever reached it. The north face of Herbert Island likewise fronts a coast which may have been continuously glaciated, but there is nothing in the topography of the north face of the island, or so far as known in its drift, to indicate that ice from the north ever bridged the water which separates it from the land to the north. Other islands in similar relations might be mentioned, showing similar phenomena. Professor Chamberlin has called attention to the phenomena of Dalrymple Island,[1] and Cone Island (Fig. 1) near the entrance of Jones Sound is equally striking.

There are then in the northern waters small islands, and their number is considerable, lying near much larger bodies of land, which appear not to have been glaciated except by ice originating on themselves.

Along those parts of Greenland where the coast is less high and rugged, and where the main ice-cap reaches the edge of the upland, it does not push out to sea as a continuous sheet, but as a series of glaciers, separated from one another by high hills of the nunatak type, though not completely surrounded by ice. These ice-free mountains stand up several hundred, and in some cases one or two thousand, feet above the ice on either side. This shows that the valleys are sufficient avenues of discharge for the ice-sheet, as now developed. The amount of snow fall and ice

[1] JOUR. OF GEOL., Vol. II, p. 661.

FIG. 1. Cone Island, Jones Sound, latitude 76° 20′, near Smith Island.

FIG. 2. A nunatak on the north side of Northumberland Island.

accumulation over the interior would need to be enormously increased before these elevations would be overridden by the ice moving out from the interior. The phenomena were such as to raise the question whether snow fall and ice accumulation could ever be so increased that the ice, moving from the interior to the coast, would override these border elevations so long as present topographic relations hold. Elevations 1000 feet high in the situations referred to would not be smothered by ice if the ice-sheet were thickened 1000 feet, since in that event the ice-drainage through the valleys would be greatly augmented, and would draw down the level of the ice immediately adjacent. It is believed that the ice-cap would need to be thickened several thousand feet before the coastal regions of the island would be completely covered.

The coast of Melville Bay is now suffering more nearly uninterrupted glaciation than any other portion of the coast seen. For a considerable distance east of Cape York it is true that three-fourths, possibly four-fifths, of the coast line is of land-ice at the present time. Yet the ice-cap lying back of Melville Bay would need to be enormously thickened in order to cover the fourth or fifth of land which is now bare.

The phenomenon of floating glacier ends, seen at several points, and heretofore referred to,[1] perhaps affords a clue to the way in which water intervals between land masses might be bridged by glacier ice, so far as they can be bridged at all. If the ice of the sea, formed by the freezing of the sea water, be not disrupted for long periods of time, the ends of glaciers crowding out into it, not being able to break off and float away as bergs, might at first float. As they advanced they might thicken, and if the water be sufficiently shallow they might ultimately rest on the bottom. With the ice of the surrounding seas still remaining unbroken, the forward movement of the ice from the land might urge the glacier ice in the water basin across the bottom of the same, and up on the opposing land. But it would seem well-nigh certain that, under the extreme conditions

[1] JOUR. OF GEOL., Vol. III, p. 875.

of climate necessary for this sequence of events, any land which the ice might invade after crossing a water interval would have an ice-cap of its own, and such an ice-cap, descending to its coasts, would come out to meet any ice-cap which might be approaching from other lands. It is conceivable that the ice-caps of adjacent lands might meet each other in the water interval now separating those lands. The line of meeting might not be midway between the two coasts, and one body of ice might have great advantage over the other. The ice of the one land mass might thus become continuous, in some sense, with the ice of another. But under these conditions all coasts would be to leeward of the ice passing over them, and the topography of leeward coasts should be recognizably different from that of stoss coasts.

The shallower the water between land masses, the easier would it be for ice from one land to bridge it and invade the other. Elevation of a region to the extent of the depth of the water intervening between two land masses, or even a little less, would obviate the difficulties in the way of continuous glaciation from the one to the other.

The phenomena of the islands of the coast of Greenland indicate that ice from the latter has not recently, if ever, overridden them. The phenomena of the Greenland coast indicate that thickening of the ice adequate even for the complete overriding of the coast has not taken place in recent times, if ever; and the phenomena, in the aggregate, raise a question as to the possibility of such overriding.

Glaciation across other bodies of water.—The same question was raised in Newfoundland. It has generally been assumed that the ice-cap from the mainland bridged the interval between Labrador and Newfoundland; but more recent studies of the glacial phenomena of the island suggest that its glaciation may have been entirely indigenous. This is the conclusion of Mr. James Howley, the geologist of the island, in spite of the fact that pieces both of labradorite and metallic copper have been found in the drift. The interior of the island is too imper-

fectly known to make it certain that both these materials may not be indigenous. It, of course, remains that the glaciation of Newfoundland may be local, without denying the possibility of the extension of ice from the mainland across even so narrow, though moderately deep, body of water as separates the island from the mainland.

Although affording no specific warrant for speculation concerning phenomena on the other side of the Atlantic, the phenomena about Greenland raise the inquiry whether continuity of glaciation from Scandinavia to the British Isles was really a fact. I am not familiar with the details of the evidence on which the current belief rests, but it seems to me difficult to believe that snow and ice could accumulate on so narrow a strip of land as Scandinavia in sufficient quantity to allow it to cross the North Sea to the British Isles, if relative elevations remained as they now are. If the water separation was much narrower and shallower than now (a result which an elevation of a few hundred feet would bring about) some of the difficulties would be obviated; but Geikie[1] finds reason for believing that the British Isles were, in general, lower than now during epochs of glaciation. Existing evidence on this point would be likely to pertain to the closing, rather than to the opening stages of an ice epoch. If the North Sea basin were overspread by a thick sheet of ice, the covering being accomplished when the land and the sea bottom were higher, a submergence considerably below the present level might be necessary to sever the continental from the island part of the ice-sheet.

Is it not true that something more than the presence of Scandinavian bowlders in Great Britain is necessary to prove continuous glaciation between these two lands? Submergence, with floating ice, might land such bowlders in Great Britain and Ireland, and they might subsequently be incorporated into till by indigenous glaciation. If there be shells in the till of Scotland which came from the bottom of the North Sea, they would seem to be good evidence of continuous glaciation across this sea

[1] Great Ice Age, 3d edition.

from the north. But may not the shells which are found be accounted for in some other way? The real question is, not how the shells in the till might have reached their present position, but how they did reach it. If Great Britain was glaciated

FIG. 3.—Profile of end of a glacier, near the head of McCormick Bay.

by ice from the northeast, its eastern and northern coasts should show the topographic features which characterize the stoss side of a land mass. The application of this criterion might be difficult, since the supposed continuity of glaciation is referred to the earlier ice epochs, the work of which has been obscured or obliterated by later glaciations, as well as by other processes. It is meant here simply to raise the question whether the evidence for continuous glaciation from Scandinavia to Great Britain does not need re-examination. Are the phenomena such as to preclude other explanations?

FIG. 4.—Side of Gable glacier near its end. East side of Bowdoin Bay.

Steep faces of glaciers.—Professor Chamberlin has repeatedly called attention to the remarkably steep faces of the average glacier in the high latitudes of the west coast of Greenland[1] (see Figs. 3, 4, 5, 6, 7, 10, and 11). I was fortunate enough to see many glaciers which Professor Chamberlin did not, and his generalization was confirmed by the facts gathered from other sources. Steep, and even vertical, faces frequently affect both the ends and the sides of the glaciers. It is not true, however, that the sides and ends of all glaciers in the high latitudes of Greenland are vertical or approximately so, though this is the general rule north of Cape York. In many cases, instead of having vertical faces, the ends and sides of glaciers slope down to the bed of the ice by steep convex curves (Figs. 6 and 7). These slopes are usually so steep as to make ascent or descent difficult, and often impossible. In a few cases only, so few as to make them conspicuous, the slopes both of ends and sides are so gentle as to allow ready ascent. In some of these cases, if not in all, the low angle was due to the exceptional accumulation of drifted snow (Fig. 8) about the borders of the glacier proper. This drifted snow had become consolidated into granular ice, so that the glacier proper had really received an addition all around its margin, giving it gentle slopes.

The phenomena of the edges and ends of the glaciers are in keeping with the phenomena of the edge of the ice-cap itself. Where the latter lies on a plain surface, its edge is not usually vertical, but its slope is so steep that ascent is difficult (Figs. 6, 8, 9). It will be seen from the figures that the angle of slope near the edge is high, but becomes rapidly less with increasing distance from the margin. Only where snow has drifted against the edge of the ice-cap, as it has done in many places, forming an extensive foot, (Fig. 8) is the slope of its edge gentle enough to make ascent comfortable at any point where it was seen.

Overhanging layers of ice.—Not only are the edges and ends

[1] Glacial Studies in Greenland, Vols. II, III, and IV, of this Journal.

FIG. 5.—Profile of a portion of the side of a glacier on the north side of Herbert Island.

of the glaciers in many cases approximately vertical, but the higher parts often overhang the lower (Figs. 3, 4, and 5). The overhang is of different types. In general it seems to be true that the overhang is dependent upon something in the structure or constitution of the ice. (1) Where the ice is made up of layers of unequal firmness, the more compact layers are likely to project out over the more granular layers beneath (Fig. 3). (2) Where there are layers of débris in the ice, the ice immediately above is likely to overhang the débris-bearing layer (Figs. 4 and 5). The overhang is usually the more pronounced the larger the amount of débris. Since the lower fourth, third, or half of the ends and edges of glaciers, as seen in section, is often full of débris, the upper half, two-thirds, or three-fourths, often overhangs the lower portion, as shown in Fig. 10.

Where the débris is in very thin zones between thin layers of ice, the overhang sometimes takes on a different phase. Here the appearance is such as to suggest that a given layer of ice has been shoved out a little over the next underlying (Fig. 11). On close examination of the ice where the photograph reproduced in Fig. 11 was taken, it was found in every case where one layer appeared to have shoved out over its subjacent neighbor, that the junction between the two was marked by a thin zone (or film) of débris. In some cases the overhang, after persisting laterally for some feet, ceased for the space of a foot or two or more (see Fig. 12), to be continued again beyond. This was sometimes repeated frequently along the contact of the layers. If the phenomenon in question were really the result of the shoving of an upper layer of ice over the one beneath, it would hardly be true that the movement would fail for a few inches (as at *bc*, *de*, *fg*, etc., Fig. 12) at frequent intervals. On cutting back into the face of the ice where this phenomenon of interrupted overhang was seen, it was found, in every case where the point was tested, that where the overhang failed, the débris between the layers also failed, and that the amount of overhang all along was in a general way proportional to the amount of débris.

FIG. 6.—A broad but very short glacial lobe from a local ice-cap near "Meteor" Bay, east of Cape York.

FIG. 7.—Profile of end of a glacier on north side of Herbert Island.

These relations led to the conclusion that the overhang in this, as in other cases, was the result of unequal melting, due to the unequal distribution of débris. The débris, being dark colored, absorbs the heat to a greater extent than the clean ice, and the ice behind the débris is therefore melted back more rapidly. As the thin zone which carries the débris is melted back, the water trickling down the face of the ice below carries the earthy matter with it. The ice just below the débris zone is coated with the finer materials washed down, and for this reason is melted back more rapidly than clean ice, and most rapidly where the coating is thickest. This causes the layer just below the débris zone to be melted back, on the whole, faster than the layer above, and to recede most rapidly at the débris level. This gives rise to the phenomena seen in Fig. 11.

Stratification and veining of the ice.—One of the conspicuous features of the ice of north Greenland is its distinct and often very conspicuous stratification (see Figs. 3–7 and 11), though there is much arrangement in layers which is not stratification, in the proper sense of the term. The layers (and veins) may be horizontal or vertical, or inclined at any angle. The arrangement of the vertical layers (veins) may be longitudinal or transverse, with reference to the glacier.

The presence of débris between the horizontal or approximately horizontal layers often helps to emphasize their distinctness, but their existence is not the result of the presence of débris. Certain layers of the ice are more solid (and blue), and certain other layers are more porous (and white). It is upon the varying texture of the different layers that the stratification in the upper part of a glacier is usually dependent, while the débris often emphasizes the distinctness of the layers in the lower portion. The horizontal layers or laminæ of ice are of variable thickness, and it would appear that the melting of ice, like the weathering of rock, often develops laminæ within layers which, in a firmer condition, appear massive. The number of laminæ is often as much as eight or ten to the inch, at the same time that layers several feet in thickness do not, in a solid con-

FIG. 8.—Edge of the local ice-cap on the peninsula between Bowdoin Bay and Inglefield Gulf. The low slope of the ice in the foreground is due to snow.

FIG. 9.—Edge of the local ice-cap north of Olriks Bay. The lower slope is snow.

dition, show conspicuous division. The horizontality of the layers is often interfered with at or near the ends of glaciers, and also at and near their lateral margins. This will be referred to later.

The vertical arrangement of layers appears to belong to the

FIG. 10.—Edge of a glacier on the southeast side of McCormick Bay, showing effect of débris on overhang.

category of veining, rather than stratification. The vertical veins appear to be altogether absent in many glaciers, and to be present in portions only of many others. Their presence or absence did not appear to depend upon any condition which affected the differentiated portion of the glacier. Indeed, if there are significant differences between the surroundings of glaciers which have vertical-longitudinal veins and those which have not, it was not discovered. The vertical-longitudinal veins were not seen in a

large proportion of the glaciers visited. Where present, they sometimes showed themselves on the surface of the ice, so that in crossing the glacier, lining parallel to its axis was conspicuous. The lining was often emphasized by the fact that certain

FIG. 11.—Edge of Tooktoo glacier, next a nunatak separating it from the Bowdoin glacier. A few miles above the head of Bowdoin Bay.

veins, presumably of less compact ice, melted more readily than others, thus developing grooves, between which the edges of the more resistant layers stood out as ridges. These vertical-longitudinal veins are of various thicknesses, but usually less than an inch. In some glaciers, notably in the western glacier of the north side of Herbert Island, there was a double ribbing of the surface, as shown in the accompanying diagram (Fig. 13). The larger swell or ridge, made up of many minor ones with their intervening grooves, seemed to be due, in some cases, to the

fact that the more solid veins composing it were thicker, and the less solid ones thinner, than in the troughs which lay beside them.

FIG. 12.—Diagrams showing how the overhangs, such as shown in Fig. 11, are interrupted laterally. The lines represent overhangs, and the interruptions represent the disappearance of the overhangs.

FIG. 13.— Diagram showing transverse profile of a small portion of the surface of the westernmost glacier on the north side of Herbert Island.

FIG. 14.—Diagram showing the wavy or sinuous course of the outcropping edge of longitudinal vertical laminæ. Same glacier as Fig. 13.

In some places these vertical ribbings on the surface were far from straight. Occasionally, as on one of the glaciers on Herbert Island, they were distinctly wavy, as shown in Fig. 14. In two cases the vertical veining was seen at the ends of glaciers, where their faces were vertical. In these sections the outcropping edges of the veins were not straight in a vertical sense. Indeed they were sometimes sharply flexed.

Vertical veins transverse to the axis of the glacier, and therefore at right angles to the series just described, were seen in several places. They affect some glaciers where the longitudinal set is wanting, and some where it is present. The two sets of vertical veins may be in different portions of the same glacier, or they may affect the same part. Where seen, the longitudinal veins were thinner than the transverse, and more continuously present.

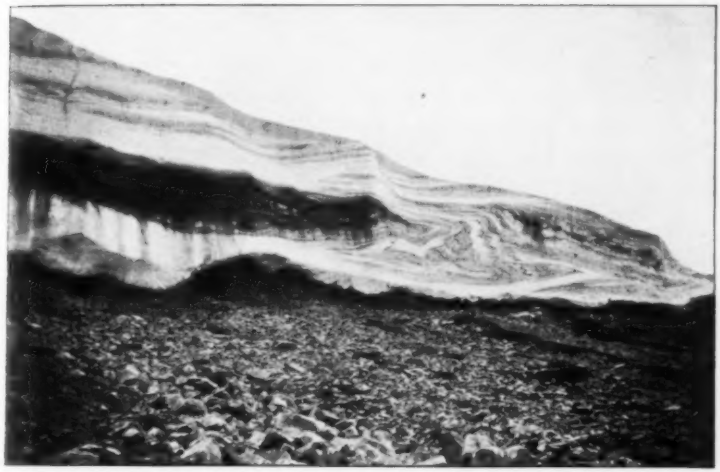

FIG. 15.—Contorted laminæ of ice in front of a lens of débris in the ice. Side of a glacier on the southeast side of McCormick Bay.

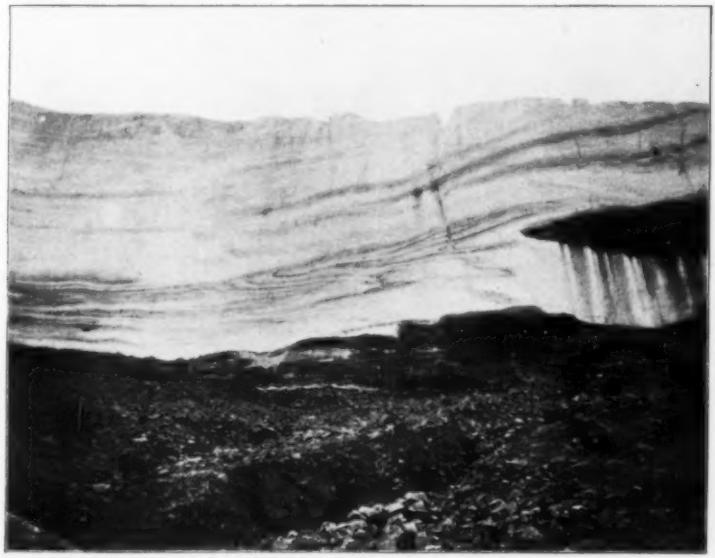

FIG. 16.—The other end of the same lens of débris as shown in Fig. 15.

The transverse veins appeared to belong to more than one category. In some cases they seemed very much like the longitudinal veins, while in other cases they seemed to be comparable to dikes. In places, these dike-like veins were as much as three or four feet thick. Locally they were of compact blue ice near their front and back walls, while the central portion was notably more granular. On the melting surface this resulted in a little ridge on either margin of the vein, with a slight depression in the center. Where a superglacial stream cut an ice gorge across one of these dike-like veins, it was often seen that the vein (or at least its walls) was of ice which was distinctly harder (and bluer) than that on either hand. As a result of its superior hardness, a rapids or waterfall was developed just below the vein, and there was a tendency to ponding above, just as in the case of a young stream cutting across a hard, vertical layer of rock. The transverse-vertical veins were nowhere seen to be contorted, or to present notably wavy outcrops at the surface.

Contortion of the layers and laminæ.— Professor Chamberlin has already called attention to the contortion of the laminæ in the Greenland ice. In the glaciers which I saw, contortion of laminæ seems to have been less general than in the glaciers seen by him. Indeed, most of the glaciers seen showed no considerable amount of contortion of laminæ, though in some cases the phenomenon was conspicuous. Its presence or absence seemed to be dependent upon certain relations, some of which at least were easily made out.

The horizontal laminæ are likely to be contorted about the considerable lenses or masses of débris which are occasionally incorporated in the body of the ice. This is shown in Fig. 15, which represents a frequently repeated relationship. Great masses or lenses of débris were rarely seen in the vertical face of a glacier, without contortion of laminæ, both behind and before, though the laminæ of ice above and below were not usually affected by contortion.

A second position in which the contortion of horizontal layers is common, is at the very base of the upper, clean part of the

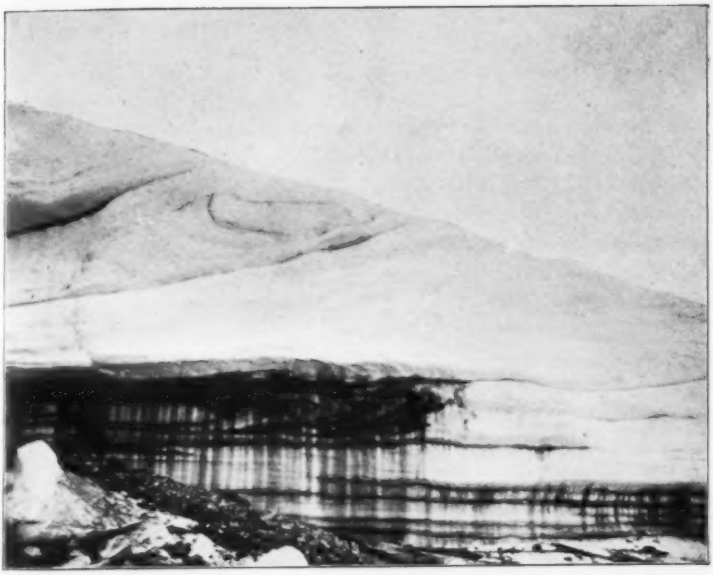

FIG. 17.— The laminæ of ice in the upturned and thickened layers are somewhat contorted. Herbert Island.

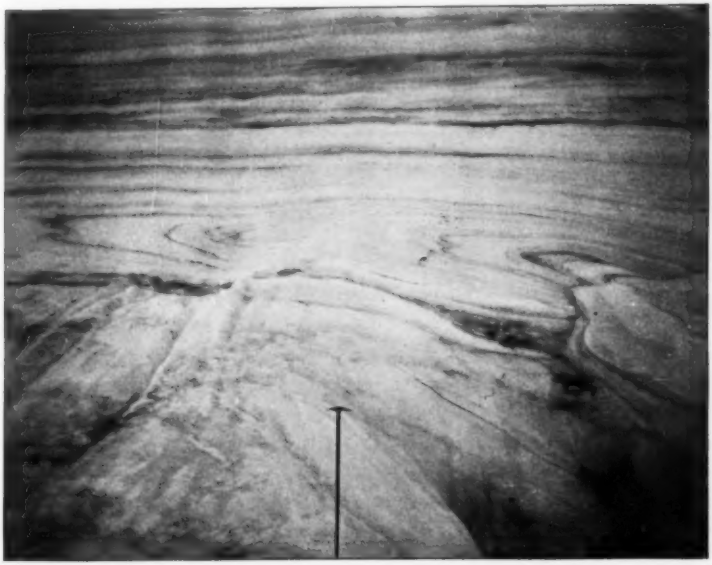

FIG. 18.— Contorted laminæ of clean or nearly clean ice. Glacier on the south side of Olriks Bay.

ice, just above its junction with the débris-charged portion below. In such cases, where a vertical section was exposed which really showed the structure of the ice, contortion was the almost universal rule.

In a few places the contortion of laminæ was seen to be

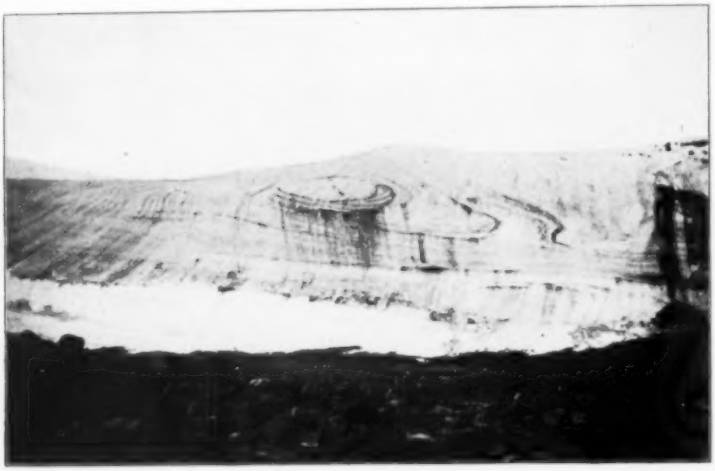

FIG. 19.— Structure resembling concretionary forms. Glacier on south side of Olriks Bay, west of the last.

striking where débris was absent, or where but little was present. This, however, is the exception rather than the rule (Figs. 17 and 18). Such a case is indicated in Fig. 6, which represents a sort of fœtal glacier — a tiny lobe projecting out from the edge of the ice-cap in the vicinity of Meteor Bay, some twenty-five or thirty miles northeast of Cape York. Attention is especially called to the position of the contortions, a position which is well-nigh universal. The bends are such as to suggest that the upper layers are crowding on faster than the lower. In a single case, only, were the contortions seen to lie in the opposite position, and this was on the opposite side of the same lobe.

The upturning of the layers of ice.—One of the striking phe-

nomena of the Greenland glaciers is the upturning of the horizontal layers at the ends and sides of glaciers. The upturning is most conspicuous as a rule at the extreme end. It becomes less and less striking with increasing distance from the end, and is not apparent at any considerable distance above. At the extreme ends of glaciers the upturning was seen to vary from a few degrees to verticality. An upturning of 30° or 40° was by no means uncommon. Higher inclinations were less frequent, and in but a single situation, namely in a glacier on the south of Olriks Bay (Figs. 20 and 21), was verticality attained. Figs. 20 and 21 represent a vertical face of ice at the end of a glacier, but the face is parallel to the axis of the glacier, not transverse to it. The same phenomenon in the same relations may frequently be seen at the sides of the glaciers. Fig. 22 shows the positions of the layers at the lateral margin of a glacier near Karnah. The layers are turned up most conspicuously at the extreme edges, and less and less markedly with increasing distance from them. So closely is the upturning confined to the lateral margins that the larger part of the surface of a glacier, even one where the lateral upturning is extreme, shows nothing of it. The upturning at the sides of a glacier is rarely equal to that at the end.

The lateral upturning is best seen at the vertical ends of glaciers. The following diagram (Fig. 23) may almost be said to represent the normal structure of a small glacier, as seen from its vertical end. If the glacier be a large one the structure shown is more likely to be that indicated diagrammatically in Fig. 24. The number of anticlines and synclines seen in cross-section in a large glacier may be several.

The upturning of the ends and edges of layers is not confined to differentiated glaciers, but affects the edge of the ice-cap as well. The edges of the main or local ice-caps were crossed in all at nine points. In seven of the nine, the marginal upturning of the layers was markedly developed. Generally speaking, it was most conspicuous where the visible amount of débris was greatest, and least where the débris was

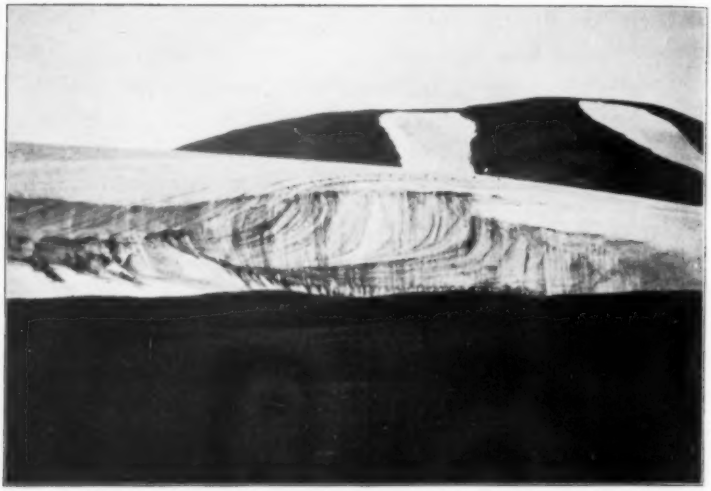

FIG. 20.—Vertical face of a glacier south side of Olriks Bay. The section is parallel with the axis of the glacier near the middle of its end. The dots on the surface are stones, lying along the outcropping edge of a layer.

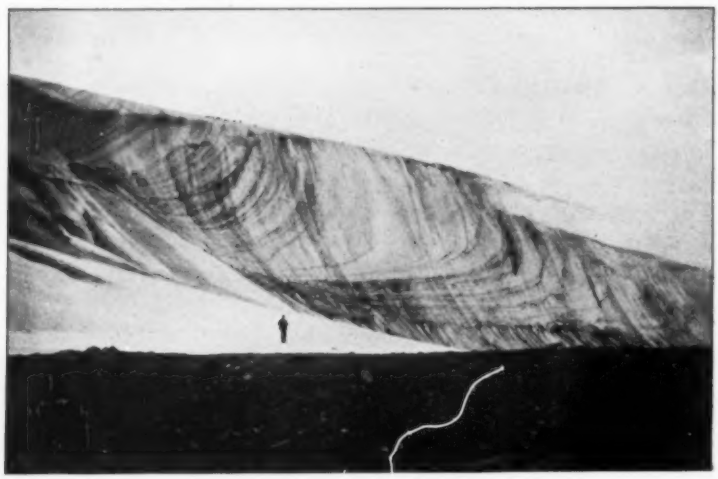

FIG. 21.—Enlarged view of a portion of 20.

absent or meager. It was not always clear, however, which was cause and which effect. On the whole it seems probable that each helped the other.

FIG. 22.—Showing the inward dip of layers of ice at the side of a glacier on Redcliff peninsula, above the settlement of Karnah.

Upturning layers of ice and superglacial débris.—The upturning of the layers of ice at the ends and edges of glaciers is often made especially obtrusive by the existence of well-defined layers of débris between them. As the upturned edges are melted, the débris in or between them accumulates on the surface of the ice along the line of outcrop of the débris zone. A small

amount of débris is shown in Fig. 20 along the line where one of the upturned layers reaches the surface. Where the débris in or between upturning layers is abundant, it is often accumulated in large quantities on the surface of the ice along the line of outcrop of the débris-bearing layer. This seems to

FIG. 23.—Diagram showing the structure of a small glacier as seen from its vertical end.

necessitate the conclusion that the drift is carried up to the surface by the upward movement of the upturned layers.

If the débris in a layer of ice, or between any two layers, were equal in amount at all points, it would appear at the surface in a continuous line or belt of drift, equal at all points. Its abundance would be dependent on the abundance of débris in the layer concerned, and on the length of time it had been bringing débris to the surface. In the course of time a very considerable ridge of drift might accumulate at the surface.

On the other hand, if the débris in or between layers of ice be more abundant at some points than at others, the accumulation on the surface would be in the form of an unequal, or possibly even a discontinuous ridge, more massive where the débris brought up is abundant, less massive where it is meager, and absent where it fails altogether. The same general rela-

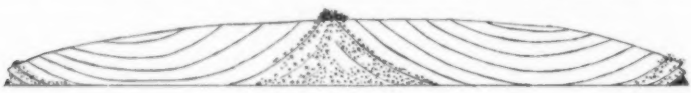

FIG. 24.—Diagrammatic representation of the structure of a large glacier as seen from its vertical end.

tions would hold concerning the upturning of the layers along the lateral margins of a glacier as along its end.

Phenomena illustrating these points were seen in many localities, both on the ice-cap itself, and on differentiated

glaciers. The edge of the ice-cap a few miles west of the upper end of Hubbard glacier showed the phenomena here referred to in simple form. Here the layers of ice at the edge of the ice-cap were upturned sharply. Between them, or between some

FIG. 25.—A ridge of superficial débris accumulated on the surface of the ice where an upturned layer reaches the surface. Edge of main ice-cap west of Hubbard glacier, Inglefield Gulf.

of them, there was débris, usually small in amount. The lines of outcrop of the débris-bearing zones were clearly marked on the surface of the ice-cap by nearly continuous lines of débris (Fig. 26). These lines were very unequal. The amount of drift coming up was much greater at some points than at others, and here the drift on the surface was piled up into very considerable mounds. Fig. 27 represents one of these mounds, something like thirty feet high, but it is probable that some portion of this elevation is due to a core of ice which is protected from melting by the drift which caps it.

Further west, and but a few miles east of Gable glacier,

where the main ice-sheet approaches the local ice-cap of the peninsula between Bowdoin Bay and Inglefield Gulf, the edge of the former shows similar phenomena on a much more extensive scale. Here drift comes up to the surface, not between all adjacent layers of ice, but only between certain layers. The

FIG. 26.—Belts of débris on the edge of the ice-cap west of Hubbard glacier. Each belt is confined strictly to the line of outcrop of an upturned débris-bearing layer.

larger part of it is in five distinct zones, which mark the outcrops of as many débris-charged horizons of ice. Each one of these belts of drift is irregular, here higher, there lower, so that each belt, instead of being a continuous and even-crested ridge of drift, is really a succession of mounds. Where the mounds attain considerable proportions, the drift spreads from their bases, so that high mounds are also always wide. Where two adjacent belts of drift are both irregular, it frequently happens that the mounds along one belt spread to such an extent that their bases are confluent with the bases of the mounds of the other belt.

These phenomena, repeated for all five belts of drift, gave rise to a peculiar and suggestive disposition of débris on the surface of the ice. Where the five belts approach each other so closely that the spreading drift of one becomes confluent with that of those adjacent, the surface of the ice for considerable areas

is completely concealed. Where this happens, the topography of the superficial drift reproduces, in all essential respects, the topography of the rough terminal moraines of the United States. Between adjacent hillocks or short ridges there are round, irregular, or elongate depressions, with sides often as steep as the

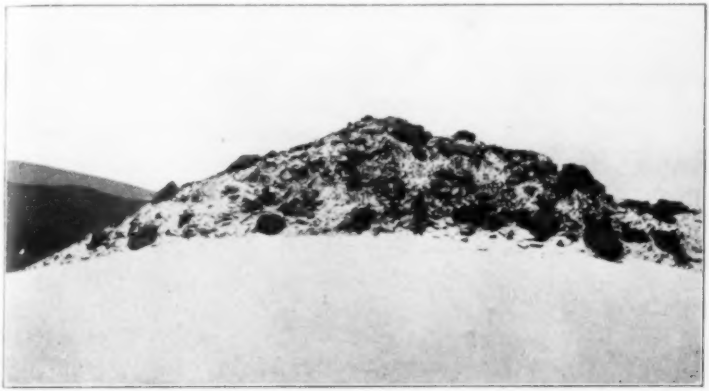

FIG. 27.—Mound of débris on edge of ice-cap near Hubbard glacier. It represents an exceptional accumulation of débris at one point, along the line where an upturning layer outcrops.

material will lie. The swells between the depressions are correspondingly abrupt. In its general contours, as well as in the specific relations of the elements of its topography, the surface drift of this locality is so like that of the terminal moraines of the United States as to suggest that, in the phenomena shown on the ice-cap at this and other points, is to be found the explanation of at least a part of the roughness of topography which characterizes terminal moraines in general. It is probably true that if the ice within the area here mentioned were to melt, depositing the drift on the surface beneath, its topography would be less rough than it is now, for it is probable that some considerable part of the elevations which appear to be of drift is really due to cores of concealed ice.

The phenomena shown on the ice-cap east of Gable glacier were shown to a less extent at various other points along the edge of the ice-cap in the vicinity of Inglefield Gulf, but best of all in the vicinity of Uminooi, latitude 76° 30′ (approximately). Here the edge of the main ice-cap was seen where there were eight of these marginal ridges of drift on the ice, sometimes separated by intervals of twenty or thirty rods, sometimes closely approaching each other. They were all gathered within a narrow marginal zone, the inner edge of which was not more than half a mile from the edge of the ice. The higher the angle of slope of the ice, the more closely did the belts of drift approach each other; the gentler the slope, the more widely were they separated. As in the locality north of Inglefield Gulf, each of these belts of drift was exceedingly irregular, being made up of a succession of hillocks, and short, or sometimes rather long, ridges, between which were depressions. Three of the depressions seen in this locality contained ponds or lakelets, one of which was fully 200 yards across. The existence of ponds in the depressions in the surface of the superglacial drift tended still further to emphasize the likeness of its topography to the topography of terminal moraines.

In this locality a single superglacial stream was found cutting through some of the belts of drift in such wise as to expose a shallow, though otherwise perfect section of the upper part of the ice below one of the belts of drift. The phenomena shown in the sides of the the little gorge are illustrated by the accompanying diagram (Fig. 28). The layers of ice beneath the drift turned up abruptly. In their upturning and movement they had brought débris to the surface, and as the ice melted this débris had accumulated on the surface, forming a ridge of drift. This ridge of drift had protected the ice beneath from melting, so that the upturned layers of ice, apart from the drift, constituted a diminutive ridge. That there was upward movement of the highly inclined layers seemed certain, not only from the relations of the débris, but from the bending of the adjacent horizontal layers.

The juxtaposition of the highly inclined and approximately horizontal layers, as shown in the figure, is explained as follows: In recent years the snow fall has exceeded the melting. Of this there was abundant evidence. Just before this condition of

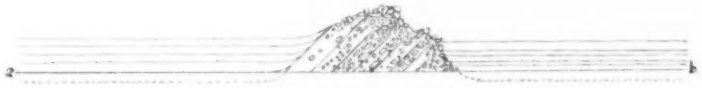

FIG. 28. Diagram showing longitudinal section of ice, as shown in the wall of the canyon of a superficial stream where the latter crossed a surface moraine.

things came about, melting had exceeded accumulation. The surface of the ice had been lowered, but the drift had protected the ice immediately beneath it, so as to give origin to a low ice ridge beneath the drift along the line of débris. It is believed that, at this stage, all the layers of ice near the edge of the ice-sheet were upturned, as they are now believed to be a little below the surface. The theoretical condition of things before the heavy snows of recent years is illustrated by Fig. 29. Later, when the snow fall exceeded the melting, the falling and accumulating snow was transformed into horizontal, or nearly horizontal, layers of ice (or névé), where it rested on ice. The drift, because of its heat absorbing qualities, helped to melt the snow which fell upon it, and its surface being elevated above that on either hand, allowed the snow to be blown off more than from the surrounding surface.

FIG. 29. Hypothetical profile of surface of Fig. 28 before the development of the overlying horizontal layers.

The drift phenomena shown on the edge of the ice-cap in association with the upturned layers, was repeated in many cases on glaciers, on the surfaces of which the upturning layers of ice had given origin to irregular and discontinuous ridges of drift.

These ridges were always near the ends of glaciers, and usually concentric with their termini, where the termini were not cut off by the waves. The surface ridges of débris, concentric with the ends of glaciers, were especially conspicuous on some of the glaciers on the north side of Northumberland Island, and on the glacier at the head of Dexterity Harbor, on the west side of Baffin Bay (Lat. 72°).

The making of lateral moraines.—Many of the North Greenland glaciers carry lateral moraines, the explanation of which is certainly to be found along the lines just indicated. In general the lateral margins of the glaciers do not touch the sides of the valleys in which they lie. Indeed they are generally separated from them by distinct intervals, and this holds well up to the heads of the glaciers. Within the stretch where the lateral margins of the glaciers do not touch the valley walls, lateral moraines have their least development near the heads of glaciers, where they are often absent, and their greatest near their lower ends. The lateral moraines, therefore, could not have been formed by the falling of débris from the valley slopes onto the ice, for of this there is no possibility. The upturning layers, as seen in cross-section, and the débris seen between these layers (Fig. 23), seem to show conclusively that the lateral moraines were formed by having material brought to the surface by the upturning and up-moving layers of ice. In some cases three of these lateral moraines lay side by side near the margin of a glacier, though more than two were rare. This statement is not to be construed to mean that this is the only way in which lateral moraines are made, but it seemed to be the prevalent way in the case of the glaciers seen in north Greenland.

Glacier load and its relations to movement.—Professor Russell[1] has called attention to the fact that the movement of ice is influenced by the amount of débris which it carries. This doctrine finds abundant confirmation in the north. The lower part of the ice, which is well charged with débris, or altogether full of it, seems to virtually lose its motion and to become the

[1] This JOURNAL, Vol. III, p. 823.

bed over which the upper ice passes. It is not possible to say that its motion is absolutely lost, but many phenomena seem to make it certain that the upper portion of the ice of a glacier passes over the lower débris-charged portion in the same way

FIG. 30.—End of a glacier on southeast side of McCormick Bay, resting on its embankment.

that it passes over a rock bed. The lower part of the ice in such cases becomes virtually an ice conglomerate, the mobility of which is certainly slight.

Morainic embankments.—The ends of many of the north Greenland glaciers appear to rest on huge embankments (or pedestals, as Chamberlin has called them) of drift, which they have constructed for themselves. The phenomenon is shown in Fig. 30. In reality these pedestals or embankments of drift on which the ends of many of the glaciers seem to rest, are less extensive than they seem. In many cases they appear to be 100

or 200 feet high, and, in extreme cases, as much as 300 feet. In the case of several glaciers, however, phenomena were seen which seem to throw doubt on the conclusion which at first sight seemed obvious. Where considerable streams plunge over the vertical faces of the glaciers, and cut gorges in this apparent embankment, it is now and then seen that the embankment is, after all, not composed entirely of drift, but that it is really glacier ice so full of débris that it has practically lost its motion, and that its outer surface only is coated with drift, free from ice. It is readily seen how this coating would be a necessity. As the débris-charged ice melts on the exterior, the débris which it held is loosened, and if the face of the ice be steep, slides down and comes to rest at such an angle as it is capable of assuming. If this process be carried on for a long period of time, the result is such as to give the impression of a great morainic embankment, when in reality much of the apparent embankment is ice, full of débris. In some sense, however, it is not wrong to look upon this apparent embankment of drift as really such, for were the ice in it to melt, a great embankment would still remain, but little less in height in some cases than it now appears; for the ice is often so full of débris that it comes to occupy only the interspaces between the stones and sand grains, and melting would not allow the drift to settle together to such an extent as to greatly diminish the height of the apparent embankment.

This conclusion is confirmed by phenomena seen at several points. In some cases small glaciers which had the habit of making these terminal embankments have disappeared or retreated, and the embankments which they had constructed, remain. This is shown in Fig. 31, which represents the morainic embankment left by an extinct cliff glacier[1] on the north side of Herbert Island. Several similar embankments occur in the same region.

In no case was the total apparent embankment determined to be of ice-filled débris, but in one place glacier ice was seen 110 feet below the apparent top of the embankment, so that the

[1] For definition of cliff glaciers, see this JOURNAL, Vol. III, p. 888.

glacier ice certainly extended that far down into the débris. The ice seen at this point, and in other gorges in similar situations, was distinctly laminated or stratified, and the laminæ were much contorted, just as in the case of glacier ice. This is

FIG. 31.—A morainic embankment, left at the terminus of an extinct cliff glacier, north side of Herbert Island.

mentioned only as indicating that the ice which cements the débris is not ice formed by the freezing of water which has trickled down from above into the débris, though in some cases this may be the fact.

It is evident that the growth of an embankment would be chiefly at the very terminus of a glacier. It is here that advance motion ceases, and it is here that all the material brought down from above must stop. It is easy to see that the débris, or débris-filled ice (which for present purposes amounts to the same thing) under the end of the active ice, might easily become higher than the bed of the glacier above. The ice would then have to push the embankment forward, or rise up over it. This probably has something to do with the upturning of

the terminal layers of ice. The same explanation would apply to the lateral margins of a glacier, where the upturning, so far as due to this factor, should be less than at the end, as is the fact.

Superglacial material.— Apart from the débris which gathers on the surface of glaciers near their ends and edges, and apart from that which gathers on the surface of the ice-cap near its edge, superglacial drift is generally wanting on the Greenland ice. Except in situations just below nunataks, stony débris was not seen at any point on the surface of the Greenland ice-caps, whether main or local, more than a fraction (rarely so much as one-fourth) of a mile back from their edges. On the surface of differentiated glaciers débris was often seen on the surface farther back from their ends, but this, in general, was in the form of medial moraines, marking the approximate line of contact between confluent glaciers, or representing material derived from nunataks, or from elevations which projected well up into the ice, but not through it, and therefore did not constitute nunataks. Occasionally there was débris in the form of medial moraines along the anticlinal part of the structure of the ice, as shown in Fig. 24.

At the very edges of the ice-sheets, and at the ends and edges of the glaciers, and in the position of medial moraines, superglacial drift was abundant, but apart from these situations there was no superficial drift on either ice-caps or glaciers, except the small amount of dust which had reached its position by the help of the wind. The wind-blown dust diminishes in quantity with increasing distance from the edge of the ice-cap, and from the ends and edges of glaciers. It is generally inconspicuous a mile or two back from the edge of an ice-cap, and inconspicuous on glaciers at any point as much as two or three miles from the nearest land surface.

That the dust was of wind origin could not be doubted, since it was absolutely free from all material which might not be readily transported by the wind, and did not affect the ice except at its surface. Furthermore, it contained, not infre-

quently, the leaves and twigs of the little shrubs which grow on the land in the vicinity.

The general absence of superglacial material on the ice-caps and glaciers of Greenland, except in situations in which débris has always been known to occur on glaciers, would seem to put an end to the doctrine which has been given currency in certain quarters that glacial débris in large quantities rises through the ice and gets upon its surface; for if the ice-cap of Greenland is free from superficial débris—except at its very margin—it would seem that the same should be still more conspicuously true of an ice-sheet on a plainer country, like our own. It is believed, however, that the phenomenon of the upturning of the layers of the ice at the edge of an ice-sheet would hold in a flat region, as well as in a mountainous one, especially where the ice was well charged with débris in its lower parts, and that this upturning would give rise to superficial drift for a few yards, or possibly a few hundred yards, back from the edge of the ice.

The disappearance of the doctrine of superglacial drift, as a general phenomenon, carries with it, of necessity, the doctrine that kames and eskers are the product of superglacial waters. On this point it should be further said that hundreds of superglacial streams, long and short, were seen on the ice-cap and on the glaciers of North Greenland, and with a single exception there was no material whatsoever accumulating in their channels. Except within the limits noted there was no drift upon the ice which the surface streams could not get hold of, nor, except at its very margins, was there drift in the ice down to the level to which the streams cut. Furthermore, the streams are almost uniformly so swift that no drift could accumulate in their channels unless it were extremely abundant on the surface. Every considerable stream seen on the ice had so high a velocity, and so smooth a bed, that even bowlders of considerable size would have been hurried along it precipitately, had they once entered the channel.

In the single case in which débris was seen in a superglacial stream channel, the amount was small and the conditions pecul-

iar. The stream was within a quarter of a mile of the edge of the ice, and flowing over the upturned edges of unequally hard layers of ice, which in their upturning had brought abundant débris to the surface. The harder layers stood up as little ridges, ponding the water above them and producing rapids below. In this stream there were trivial patches of gravel in the ponded portions. Even here there was nothing to suggest the development of an esker or a kame. There seems, therefore, to be no warrant in the phenomena of North Greenland, so far as known, for the belief either that there is, or can be, much superglacial till, or that superglacial streams can do much in the way of depositing stratified drift.

Physical and chemical condition of superglacial material.—The statement has often been made that superglacial material is highly oxidized and weathered, and that, on the basis of these characteristics, it may be distinguished from subglacial material, even in the drift deposits of the United States. This has been repeatedly cited as a criterion for the recognition of superglacial drift. This point was in mind during the study of the glacial phenomena of Greenland, and it may be emphatically stated that the superglacial drift of that land is not noticeably more oxidized and weathered than the subglacial. Where superglacial drift occurs, it appears to be as fresh, and its elements as firm in every way, as the subglacial material to be seen but a few rods away.

Lack of wear has been thought to be a mark of superglacial, as distinct from subglacial, bowlders. But the superglacial drift seen was often, though not always, as distinctly and thoroughly worn as the subglacial. This never appeared to be true where the superficial material arose from a nunatak, or from a hill or a mountain which just failed of being a nunatak, but it was generally true where the material on the surface had been brought up from the bottom by the upturning layers.

Glacial drainage.—Another striking feature of the north Greenland glaciers is the fact that the drainage from them does not behave altogether as drainage from glaciers is commonly supposed to. In the first place it is the rare exception that a

visible stream of any size issues from beneath a glacier at its end. That water really issues from the end of the glacier and flows on beyond can hardly be doubted, but in general it escapes beneath or through débris, rather than over it. In some cases, indeed, in crossing the embankment slope in front of the end of a glacier the motion of the water in the drift beneath one's feet can be heard.

As before noted, the sides of a glacier rarely rest against the valley in which the ice-stream lies, and in the gorge between the ice on the one side, and the valley wall on the other, there is usually a stream. These lateral streams are tolerably constant accompaniments of the glaciers, as Chamberlin has already pointed out.

Surface ablation does not give rise to many considerable streams on the surface of the ice. The surface is usually so crevassed that the water plunges beneath it soon after its formation, and the stream which continues for more than a few rods on the surface is the exception rather than the rule. Cases were however seen where superficial streams were continuous for some miles. The longest seen was on the surface of the largest glacier on the north side of Herbert Island. Here, in the summer of 1895, a stream was essentially continuous from the head of the differentiated portion of the glacier to a point near its terminus.

Englacial drainage does not show itself so long as the drainage is englacial, but the fact of englacial drainage was shown at several points. The most conspicuous example seen is shown in the accompanying figure, which represents the end of a large glacier on the south side of Olriks Bay. Here, as will be seen, a huge spout of water issued from about the middle of the vertical face at the end of the glacier. The diameter of the stream as it issued from the ice was about five feet. Issuing approximately horizontally, it showed that there was an englacial stream of similar proportions behind it. In such a case there is of course no means of knowing the length of the englacial stream, or how nearly it maintains its horizontal position. The

force with which the water shot out, in this particular instance, indicated plainly enough that it was under great head. In this case the stream was very red, due to the fact that it contained much sediment, or rock flour, arising from the comminution

FIG. 32. End of the large glacier on the south side of Olriks Bay. Englacial stream issuing.

of the red rock over which the ice had moved. Since the stream issued from the ice at a level quite above any considerable amount of débris, it would appear that somewhere in its course the water must have been at a relatively lower level in the ice, flowing, throughout a portion of its course, sufficiently near the bottom of the glacier to acquire the silt which it contained.

That englacial water sometimes does flow under great pressure was shown by a phenomenon seen on one of the glaciers near Godhavn on the island of Disco. Here from the upper

surface of the glacier there welled up a huge spring (Fig. 33). The water shot up not less than ten feet above the bottom of the basin whence it issued. The water was intensely red, owing to the presence of the flour of red rock which the ice had ground

FIG. 33. Spring on the first glacier in the valley above Godhavn, Disco.

up. The upper part of the ice was nearly free from débris, and the water must have risen from a lower horizon in the ice. The inconstant character of englacial drainage is shown by the fact that two months later, at the same site, there was no suggestion of a spring. The water had found some other avenue of escape, though the basin and the opening in its bottom were easily found. The opening was about five feet in diameter, and for a distance descended nearly vertically.

Kames and eskers.—No esker was seen in Greenland, nor was any process observed which would at any time result in the formation of an esker.

Except in one situation, namely, on the north side of Olriks Bay, no kame was seen. Here there were some kame-like hills on a surface which had been abandoned by the ice, but no process was seen in operation along the margin of the ice at any point which seemed to throw special light on the origin of this class of drift hills.

The surface over which the ice has retreated.—In a number of places, surfaces were seen which have been, within relatively

recent times, covered by the ice, but which are now free from it. Such surfaces were seen on the Redcliff peninsula, and on the peninsula east of Bowdoin Bay; but in no case where the abandoned surface was seen did it appear to be true that its topography was fashioned by the drift. The main features, at least where there were roughnesses, seemed to be due to the underlying rock, and the effect of the drift, on the whole, was rather to level the surface than to roughen it. In general the topography of the drift on surfaces abandoned by ice-sheets, so far as it could be differentiated from the topography of the underlying rock, was nearly plane.

There were, however, minor details of surface which were notable. It was frequently to be seen that the drift of a surface recently abandoned by the ice was disposed in a multitude of tiny crescentic ridges, concave toward the ice. The ridges were one to ten feet wide, and one to ten yards long. They were generally no more than one or two feet high, and just within the crescent there was likely to be a depression of perhaps an equal amount, so that the generally flat surface still had a relief of two to four feet. This was perhaps the most conspicuous minor detail observable on the surface of the drift. Much of the drift-covered surface of the flat uplands looked as if a heavy roller had been passed over it. Much of the surface which had been recently freed from ice was essentially without relief.

On the whole, the drift in Greenland is notably more stony than the drift of our own country. Clay, due to the grinding of the rock, was everywhere conspicuous by its paucity or absence.

ROLLIN D. SALISBURY.

THE GENESIS OF LAKE AGASSIZ.[1]

In a paper read before the Geological Society of America on December 28, last, entitled *The Relation between Ice-Lobes South from the Wisconsin Driftless Area*, Mr. Frank Leverett[2] appears to have made some very interesting records of the relative ages of the sheets of drift in Illinois and vicinity. As these are directly in line with the observations made by me during the past few years in Manitoba, and throughout the country northward lying west of Hudson Bay, a few notes on the conclusions to which these observations tend may be of interest in advance of the publication of my detailed reports and maps by the Geological Survey of Canada.

In a short paper published in the *Geological Magazine* for September 1894, based on the explorations of 1892 and 1893, the writer outlined the existence, during the Glacial Period, of a great glacial center or gathering ground lying comparatively close to the west coast of Hudson Bay, from which the ice radiated in all directions; eastward into the basin of Hudson Bay, which was probably an open body of water then as it is now, and furnished the moisture for the immense precipitation of snow a short distance to the west of it; southward towards Manitoba and the Great Plains; westward towards the Athabasca-Mackenzie Valley and the Rocky Mountains; northwestward and northward[3] toward the Arctic Ocean.

A second expedition by the writer through the same or adjoining country in 1894 served to corroborate and strengthen the conclusions reached in the preceding years. At or near the

[1] Published by permission of the Director of the Geological Survey of Canada.

[2] Abstract in American Geologist, February 1896, p. 102.

[3] Notes to accompany a Geological Map of the Northern portion of the Dominion of Canada, by GEORGE M. DAWSON, Ann. Rep. Geol. Sur. Can., Vol. II, 1886, Part E, p. 57.

center of glaciation the striæ were found to be very indefinite, and to have changed in direction as the center slightly shifted its position, but no evidence of any other general glaciation could be found, or that the ice had left the country uncovered from the beginning to the close of the Glacial Epoch.

In the *Geographical Journal* for November 1895, p. 439, I have used the name Keewatin glacier for this continental ice-sheet, as its center lay in the northern portions of the District of Keewatin, and I shall continue to use that name, with the understanding that if it prove to be the same as the ice-sheet of the Kansan or Iowan period it will give place to one of these prior names unless indeed both of the latter should be found to represent re-advances of the same glacier, in which case the name "Keewatin" might conveniently be retained. At the same time I would suggest that Dr. Dawson's name "Laurentide Glacier" be restricted to that great *mer de glace* centering over the country north of the St. Lawrence River and the heights of Labrador.

A portion of the former glacier, advancing southward or southwestward, came in contact with the high escarpment of Cretaceous shales in western Manitoba, and by it was diverted more to the eastward, taking the trend of the great valley of Lake Winnipeg and the Red River. In this direction it appears to have advanced far into Minnesota, Dakota, and Iowa. The Palæozoic limestones of western Manitoba are beautifully scored by its markings, and its grooves and striæ were detected in many places as far east as the east side of Lake Winnipeg. East of Lake Winnipeg the exposed surfaces of the Archæan rocks were carefully searched for this set of markings, but none could be detected. It therefore seems probable that the eastern edge of this lobe or portion of the Keewatin glacier did not extend very far east of the present eastern shore of Lake Winnipeg, and it is also probable that throughout its advance there was a free drainage eastward, probably into Hudson Bay.

Traces of the existence of the streams that flowed eastward from the face or side of this glacier were found in several places in the form of deep pot-holes excavated in the summits or on

the eastern slopes of knolls of granite and gneiss, where they could not have been formed by the present streams or by others, like them, flowing westward. At one place, on the south side of Berens River, several of these pot-holes occur on the east side of a granite knoll, one of them, at least, being ten feet in depth, and about thirty inches in diameter from top to bottom. On the same side of the knoll, facing up the present stream, was a well-marked water-worn groove, leading down to a shallow pot-hole at the foot of the hill. The ten-foot hole was cleaned out and was found to contain a great number of well-rounded pebbles, all of Archæan rocks, some similar to the rocks of the surrounding country and others that had evidently been transported from a distance. Both this and the other rocky hills where the pot-holes were seen have been eroded and scored by the later glacier from the east, the outer sides of some of the holes having been cut away, leaving rounded niches in the faces of the smooth hillsides.

After occupying the basin of Lake Winnipeg and the Red River Valley for an uncertain but doubtless long period of time, the Keewatin glacier began gradually to retire. As it retired a portion of the Laurentide glacier, which in the meantime had been accumulating in the country farther east, perhaps in the high land of the Labrador peninsula, gradually advanced. The Keewatin glacier seems to have retired northward well into Manitoba, and possibly even beyond the northern limit of that province, before it was joined by the eastern glacier. When they united the water was ponded between the fronts of the two glaciers to the north and east, and the high land to the south and west. Thus Lake Agassiz had its beginning. Its waters rapidly rose until they overflowed southward into the valley of the Mississippi and then gradually declined as the river Warren deepened its channel.

After the union of the two glaciers the Keewatin glacier may have remained stationary for a considerable period, during which time the strong ridge extending from Long Point westward between Cedar and Winnipegosis lakes and beyond, apparently

crossing the Saskatchewan River at the Pas, was formed in the bed of this lake.

Meanwhile the eastern glacier was advancing towards its extreme western limit near the west shore of Lake Winnipeg, for it never crossed the belt of land intervening between that lake and lakes Manitoba and Winnipegosis. Before it reached the mouth of the Saskatchewan River, on the west side of this lake, the Keewatin glacier had already retired a considerable distance farther north, a sufficient time having elapsed to permit of the deposition in the bed of the lake of at least twelve feet of thinly and evenly stratified sands and clays over till of the earlier glacier, before they were covered by the till of the later glacier. The section of these two tills, with the intermediate stratified deposits, is well exposed on the bank of the Saskatchewan River near its mouth, and has been described by the writer in his "Report on Northwestern Manitoba."[1]

The later history of Lake Agassiz has not yet been definitely determined, but it would seem reasonably certain that the Keewatin glacier continued to retire northward until it separated from the eastern glacier. Then the water would drain freely around the northern end of the latter glacier to Hudson Bay. The northeastern drainage has been shown by Mr. Upham[2] to have begun at the level of the Blanchard Beaches, the highest of which, along the line of the Manitoba and Northwestern Railway, is stated to be at an elevation of 994 feet above the sea or 284 above the present level of Lake Winnipeg. The eastern glacier seems to have now begun to retire, and its front had retired to a short distance east of the east shore of Lake Winnipeg when the Burnside and Gladstone Beaches were formed at elevations of from 150 to 170 feet above the present lake. Stratified Lake Agassiz sands and clays were deposited in considerable thickness on this side of the lake up to the above level, apparently near the front of the glacier. That the eastern glacier

[1] Ann. Rep. Geol. Sur. Can., Vol. V, 1890-1, Ottawa 1893, Part E, p. 140.

[2] Report of Exploration of the Glacial Lake Agassiz in Manitoba, by WARREN UPHAM, Ann. Rep. Geol. Sur. Can., Vol. IV, 1888-9, Part E.

had not retired further east during the time when Lake Agassiz stood at a higher level is shown by the absence of stratified lacustral deposits above the 150–170-foot line, in many places only a very few miles from Lake Winnipeg, an absence peculiarly noticeable as these deposits occur in such abundance below that line.

It is thus seen that the Keewatin glacier, which centered west of the northern part of Hudson Bay, had extended southward to its furthest limit, and had then retired many hundreds of miles, probably more than half way to its gathering ground, before the Laurentide glacier had reached its greatest extension.

Dr. Dawson[1] has also shown that the Cordilleran glacier reached its greatest extent and retired before bowlder-clay that generally underlies the western plains was deposited. This bowlder-clay I take to be the true till or ground moraine of the Keewatin glacier, when this glacier had reached its greatest extent in a southwesterly direction.

The evidence at present at hand would therefore seem to strengthen the view that in the northern part of this continent during the glacial period there were three great centers of snow and ice accumulation, one, the Cordilleran in the mountains of British Columbia, a second, the Keewatin, on the comparatively low land northwest of Hudson Bay, a third, the Laurentide, in the Labrador Peninsula.

Beginning at the west, and going eastward, these three great glaciers would seem to have reached their widest extent and retired in succession. Still further east, across Davis Straits, a fourth great glacier, probably similar in character to those that have disappeared from the American continent, covers Greenland at the present time.

J. BURR TYRRELL.

[1] Glacial Deposits of Southwestern Alberta, in the vicinity of the Rocky Mountains, by GEORGE M. DAWSON, Bull. Geol. Soc. Am., Vol. VII, pp. 31–66. Nov. 1895.

LACCOLITES IN SOUTHEASTERN COLORADO.[1]

THE western part of Colorado is mountainous; the eastern belongs to the Great Plains. The plains are in part smooth, as the name implies, and in part broken by canyons and diversified by valleys, cliffs, and terraces. Near the southeast corner of the state is a broad upland plain, bounded on the north, south, and west by bluffs that overlook lowlands with diversified relief. The plain slopes gently toward the east and is furrowed here and there by streams flowing in the same direction. Its determining formation is an alluvial deposit of sand and gravel, believed to be of Neocene Age. This rests on an eroded surface of Cretaceous and Juratrias rocks, and these rocks are exposed in the surrounding lowlands as well as in the channels of the dissecting streams.

Previous to the modern dissection the alluvial plain must have been remarkably even, but a few knobs of resistant rock projected above it, and one of these now stands so high as to constitute a conspicuous landmark. Twin Butte, or Two Buttes as it is sometimes less aptly called, is conical in its general form but has a double summit. Past its southern base flows Two Butte Creek, and the rock exposures are continuous from the butte to the creek. The crest of the butte is 350 feet above the plain and 600 feet above the creek. It stands in west longitude 102° 33′ and north latitude 37° 39′.

Visiting the locality in September 1895, I found the butte to be capped by a block of sandstone which had acquired exceptional hardness through association with a local occurrence of igneous rocks; and a hasty examination of neighboring exposures discovered such an arching of the Mesozoic strata as to

[1] The observations here communicated were made in connection with field work of the U. S. Geological Survey, and are published by permission of the director.

Proof of this article has not been read by the author.— ED.

indicate the presence of laccolites of some magnitude. The following month I returned to the locality in company with Mr. F. H. Newell, and we spent a week in local surveys and studies. A contour map of the locality was made, the thicknesses of the sedimentary formations were measured, and all outcrops were platted. By combining these data it was found possible to construct an approximate contour map of the deformation of the upper strata, and thus estimate the total volume of the intrusions.

The following is the sedimentary section as determined by Mr. Newell:

5. Olive, purple, and pink shales, with beds of fine-grained yellow sandstone, and one or more bands of concretionary impure limestone. The sandstone contains large, beach-rolled, silicified logs. From the upper shaly layers were obtained invertebrate fossils, recognized by Mr. T. W. Stanton as of Dakota age. The top of the formation was not seen, - - - - - - - - - 100 ft.

4. Sandstone, fine-grained, chiefly massive but partly bedded, of variable color. On the east side of the dome all zones of the sandstone are bright red, and this is probably their normal color; but the different layers, as they approach the base of the Neocene sands, become yellow, and in some places white. On the southwestern slope of the dome, a shale forty or fifty feet thick parts the sandstone into two groups, of which the lower retains the characters just described, while the higher has a prevailing dull yellow color, and is in part vitreous, as though modified by igneous intrusion. A similar distinction was seen at the north, where most of the upper member has the character of quartzite, and the yellow color is replaced by gray, - - - - - - - - 380 ft.

3. Brick-red shales, arenaceous at top and passing by gradual transition into No. 4. Soft and easily eroded, except in the immediate vicinity of igneous masses, - - - - - - - - 150 ft.

2. White limestone, - - - - - - - - - - 5 to 10 ft.

1. Yellow, red, and orange, thin-bedded shales and sandstones. The shales probably exceed the sandstones in thickness, but being largely arenaceous, they assume the character of sandstones in the vicinity of igneous intrusions. The bottom of the series was not seen, - - - - - - - - - - - - - 100 ft.

Total, - - - - - - - - - - - - 740 ft.

No fossils were found below No. 5, and our present knowledge of the general stratigraphy of the surrounding country does not warrant a definite correlation of the formations. A few miles farther north the Dakota formation is exposed in a broad belt, beyond which it dips under the Benton shales.

Two Butte Creek, which in general has a comparatively open valley, passes at this point through a box canyon sixty feet deep, and in the walls of the canyon the three highest formations are seen to arch regularly from west to east. They are also seen to dip southward, so that the structure revealed by the canyon is essentially part of a quaquaversal arch. Scattering outcrops of various formations at the north accord with this theory, and further confirmation is found in the vicinity of the butte, where some of the highest ground, excepting the butte itself, is occupied by the lowest formation, No. 1. The white limestone (2), which outcrops in the creek valley with southerly dip, is also found at the southeastern base of the butte, where it is nearly level; and the crest of the butte consists of the lower division of the red sandstone (4) which there dips to the west. By combining the stratigraphic and hypsometric data it was found possible to estimate at many points on the sheet the height to which the upper formations had been lifted; and with further aid from observed dips, contour lines were drawn to represent the figure of deformation. These contours appear in Fig. 5, where a distinction has been made between the parts practically fixed by the observed data and other parts interpolated with a free hand. So many minor inflections were found in the district exposed to direct study that we may suppose the actual contours to be much less regular than those supplied for the regions covered by the Neocene sands. At several points there are local flexures, giving dips of fifteen or twenty degrees, and it is probable that a fault traverses the western slope of the butte.

The formation thus determined has a basal breadth in any direction of from five to five and a half miles. Its central height is from 1000 to 1200 feet, the smaller estimate being derived from the northwestern slope, the greater from the eastern

and southeastern slopes. In neighboring regions the Cretaceous formations are characterized by flexures and dislocations of minor importance, and it is probable that a deformation of that general character is here combined with the arching due to igneous intrusion. A computation based on the contours of deformation indicates the total volume of the uplifted or protuberant mass as a little less than one cubic mile.

The igneous rocks associated with this local uplift include laccolites and dikes. There are at least two laccolites, and the number may be much larger. The highest is known only by a remnant exposed at various points about the southeastern base of Twin Butte where it rests on the white limestone (formation 2) and is covered by red shale (3). It does not appear on other sides of the butte, and it is probably limited on the west by a fault. The steep westward dip of the overlying strata suggests that the mass may originally have been large. Beneath it, and separated only by the white limestone, is a broad mass whose upper parts only are seen. Its outcrop is nearly continuous for three-fourths of a mile from north to south and more than half a mile from east to west. Wherever its relations to the sedimentaries are seen it passes beneath them, the overlying strata being either formation 2 or some member of formation 1. South of this area is a smaller tract of igneous rock which may represent a laccolite or a sill; and beyond it is the irregular exposure of an intrusive mass which ranges in thickness from fifteen or twenty to more than 100 feet and traverses the formation obliquely so as to be walled in places by formations 1, 2, and 3. It is possible that the larger of the observed laccolite masses is the principal intrusion, occupying practically the whole interior of the dome; but consideration of the irregularities of the deformation leads rather to the view that the arch includes a number of individual masses.

About fifty dikes were noted traversing parts of the dome, and it is probable that others intersect the laccolites. One dike was seen at a point two miles beyond the northwest base of the dome, and at another point outside the dome a well sunk through

the Neocene sand brought up igneous rock of the same general type. The majority of the dikes trend approximately at right angles to the strike, so that if produced they would pass near the center of the uplift; but on the southwestern slope of the dome a small group trend approximately with the strike.

In the various characters thus far mentioned the Twin Butte laccolites do not differ from the ordinary type, but petrographically they are rather exceptional, and their peculiarity of rock type is the occasion of geomorphic characters which are equally notable.

Classifying igneous rocks broadly as basic, intermediate, and acid, most of the laccolitic rocks heretofore described belong to the intermediate group, a smaller number are acid, and basic examples are comparatively unknown. R. C. Hills characterizes as doleritic two small masses observed in Huerfano Park, Colorado,[1] and Weed and Pirsson have described large laccolitic masses, occurring in the Highwood, Little Belt, and Bearpaw mountains of Montana, in which the outer parts are basic and the inner acid.[2] The Twin Butte rocks also are basic and closely resemble some of the Montana types. As the chief mass is so little dissected that all collections were from the upper part, it is quite possible that the new locality belongs structurally with the type discovered by Weed and Pirsson.

The specimens collected have been placed in the hands of Mr. Whitman Cross and are to be studied in connection with cognate rocks obtained by myself and others from a great system of dikes occurring in areas to the west and south of the locality under consideration. As the result of a preliminary examination he informs me that they are properly designated syenite-porphyry. The essential constituents are biotite, augite, and alkali feldspars, and as the ferro-magnesian minerals predominate, the rocks are basic. They are porphyritic in structure, and large phenocrysts of biotite are characteristic.

[1] Proc. Colorado Scientific Soc., Vol. III, Part 2, p. 226, 1889.

[2] Bull. Geol. Soc. Am., Vol. VI, pp. 389–422 (1895); Am. Jour. Sci., 3d ser., Vol. L, pp. 467–479 (1895); 4th ser., Vol. I, pp. 283–301, 467–479 (1896). The authors refer also to descriptions of European localities.

Fragments of various rocks are included in the laccolites and dikes, and are of interest as revealing the nature of lower-lying terranes through which the ascending liquid passed. Besides sandstones and shales similar to those constituting the wall rocks, the most abundant as well as the most notable rock is a porphyritic granite with conspicuous crystals of gray feldspar.

The age of the laccolitic intrusion is not closely determined. The youngest formation involved in the deformation is the Dakota. The Neocene sand rests undisturbed on the worn edges of the deformed strata. Manifestly the intrusion was subsequent to the one and antecedent to the other. These limits stand wide apart, but a little consideration will show that the epoch of intrusion was probably not close to either. In discussing the laccolites of the Henry Mountains, the writer reached the tentative conclusion that a heavy load of overlying rocks was a condition essential to the formation of a large laccolite, and the body of data which has since been gathered is rather confirmatory of this conclusion than otherwise. If this be admitted we must assign to the intrusion a date at which the Dakota sandstone was covered to a great depth by other formations. It is known from the general history of the region that the deposition of the Dakota was followed by that of the Colorado and Montana groups, and it is possible that these were here succeeded by the Laramie also. Subsequently all these beds were eroded, not only from this particular district but from an extensive tract of the Great Plains province, and much time was necessarily consumed in this work. It seems therefore probable that the date of the igneous intrusion belongs either to the closing epochs of the Cretaceous period or to the earlier half of the Eocene period.

The porphyrites and cognate rocks which elsewhere constitute the greater number of laccolitic masses are notable for their durability. Not only are they so hard as to resist corrasion stubbornly and cause the diversion of such small streams as may chance to flow athwart them when they are discovered by the general degradation of the country, but they yield with

extreme slowness to the ordinary processes of disintegration. It results that in regions of rapid degradation laccolites usually survive all associated rock-masses and find topographic expression in steep-sided mountains or buttes. In these respects the rock of the Twin Butte locality is strongly contrasted. It weathers more easily than the associated sandstone, so that dikes traversing sandstone outcrops are sometimes not easy to trace; and it is scarcely more durable than the associated shales. The dikes do indeed stand prominent above shale areas, but this is occasioned largely by the baking of the shales along the planes of contact, and also in part by an alteration of undetermined character which in some instances affects the dike rock for a few inches from the planes of contact. Where the laccolites are in contact with shales the latter are modified for many feet or yards, being rendered much more durable than the igneous rock. It results that the exposed parts of laccolites, being weaker than all the associated sedimentaries, are characterized topographically by valleys.

I. C. Russell, reasoning from the dominance of acid rocks among laccolites, the frequent occurrence of basic rocks as thin sheets, and the viscosity of acid magmas as compared to basic at the same temperatures, has recently suggested[1] that great viscosity is an essential condition of the production of thick intrusive lenses. As this theory encounters serious difficulty in the new data from Montana and southeastern Colorado, I venture an alternative suggestion involving a different point of view. The topographic features associated with the weak basic rocks at Twin Butte are inconspicuous, whereas those of the resistant porphyrites of the Elk and Henry mountains are bold and striking. Is it not possible that the basic rocks are really well represented in laccolites, but have as yet received little notice because in the gradual development of the subject the more salient features have first caught the eye?

G. K. GILBERT.

[1] JOUR. GEOL., Vol. IV, pp. 179–180, 1896.

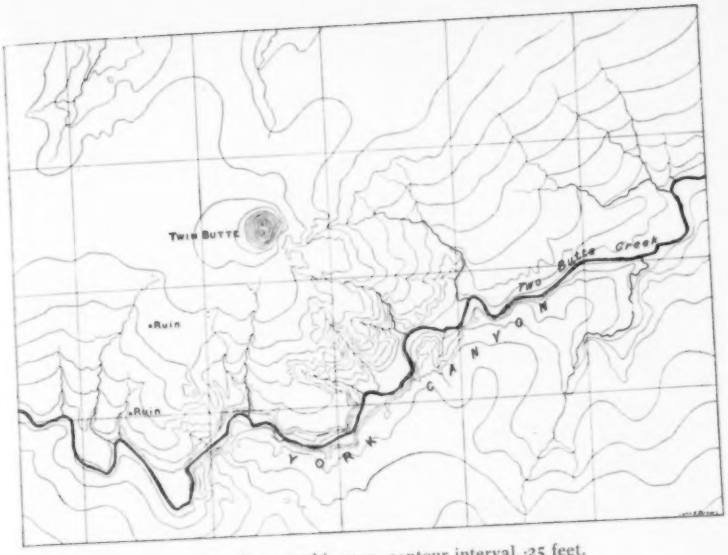

FIG. 1.—Topographic map, contour interval, 25 feet.

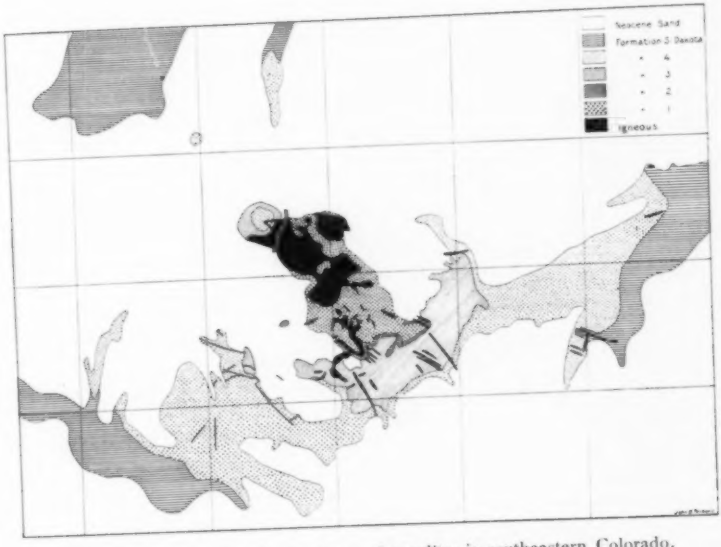

FIG. 2.—Geologic map of same area. Laccolites in southeastern Colorado.

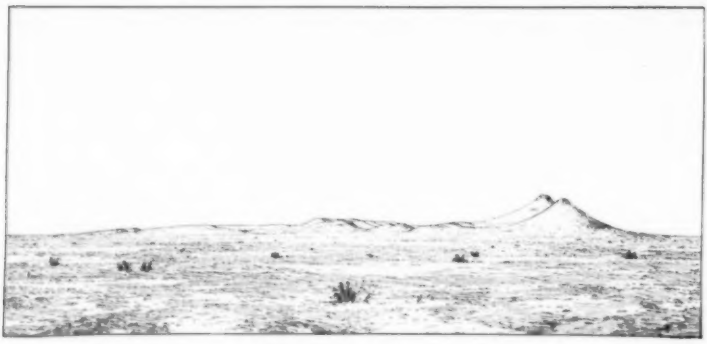

FIG. 3.—Twin Butte and the crest of the arch, from a point on the plain two miles northeast.

FIG. 4.—Ideal cross-section of igneous intrusion.

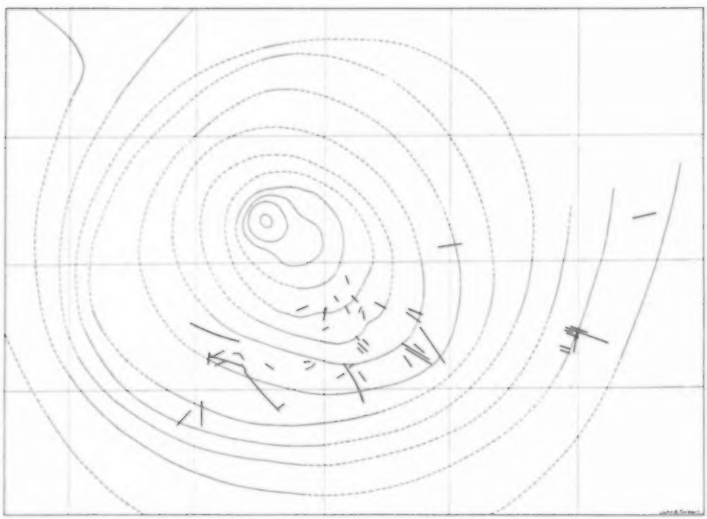

FIG. 5.—Deformation map. See explanation at end of text. Laccolites in southeastern Colorado.

EXPLANATION OF FIGURES.

All of the figures except the landscape view have the same scale. Each of the three maps represents the same area. To aid in their comparison vertical and horizontal lines are drawn at intervals corresponding to one mile.

FIG. 1. Map of Twin Butte and vicinity, showing the topographic relief by contour lines at every 25 feet.

FIG. 2. Geologic map of Twin Butte and vicinity, showing the distribution of the surface formations described in the text.

FIG. 3. Landscape. In the foreground the plain of Neocene alluvium. At the right, Twin Butte. At center and left, the crest of the laccolitic dome, dissected by drainage flowing in the direction from the observer and descending rapidly to Two Butte Creek. The rocks capping these low hills are shales hardened by reaction from the laccolite beneath.

FIG. 4. Ideal cross-section of the igneous intrusion, from east to west. The profile of this is constructed from the contours of deformation (Fig. 5) on the assumption that the intrusives constitute a continuous mass dividing the sedimentaries at a single horizon. It is known that this assumption is not strictly true, but the meager data at command do not suggest an improvement. The diagram shows for each point the total uplift of the cover and therefore the total thickness of intrusive rock.

FIG. 5. Deformation map of Twin Butte and vicinity, showing, by means of contours at intervals of 100 feet, the form which would appear if the eroded parts of formation 3 (Fig. 2) were restored, and all overlying formations were removed. Where the positions of the contours are controlled by the geologic data the lines are full. The broken lines are interpolated. The other lines of the figure mark the position and trend of dikes.

ITALIAN PETROLOGICAL SKETCHES.

II. THE VITERBO REGION.

Bibliography.—The writings of the early Italian geologists, such as Brocchi, Pareto, and Ponzi, are of such small petrological value at the present time that nothing need be said of them here.

The first to describe the region according to more modern methods was vom Rath,[1] who devoted parts of two of his Italian *Fragments* to its description. This is largely topographical, but contains many petrographical details and some analyses, which will be referred to later. Stoppani[2] also, in 1873, gives a brief account of the region.

Through the kindness of Sig. Caposavi I was enabled to obtain a copy of Dr. Barbieri's pamphlet, entitled *I Vulcani Cimini e Vulsinii* (Viterbo, 1877), which is out of print and very rare. It proves to be a popular but graphic sketch of the geological history of this and the Bolsena regions.[3]

In 1880 A. Verri[4] published a somewhat extended description based on personal observations. Accompanying it is a geological map, which is on a small scale, and a much idealized section. His petrographical determinations are not based on microscopical examination of thin sections, and hence leave much to be desired. After the descriptions of the various rocks and remarks on their distribution, he gives a sketch of the Tertiary and post-Tertiary history of the volcano, as he deduces it from his observations.

[1] VOM RATH, Zeit. d. d. Gesell., XVIII, 577–585, 1866; XX, 294–307, 1868.

[2] Corso di Geologia, Milan, 1873, III, 387.

[3] This is mentioned since the work is scarcely known, and the bibliography published in the Boll. Com. Geol. Ital. for 1886 mentions it only by title.

[4] VERRI, Atti Acc. dei Lincei., VIII, 3–34, 1880.

A few analyses of eruptive rocks from this center were published in 1884 by Ricciardi,[1] but, as he expressly states that they are of groundmass carefully freed from phenocrysts, they are unfortunately of comparatively little use to us.

A few years later Bucca[2] published some short petrographical descriptions of various rocks from this locality. He concludes that two distinct types are found in the region, "one essentially trachytic, the other leucitic. These two types often appear isolated and clearly distinct; at other times there has been a mixture of one with the other." He further thinks that the trachyte is younger than the leucitic rocks and argues from this an increase in acidity during successive eruptions.

In 1889 appeared the latest works on this region so far as my knowledge extends. The paper by G. Mercalli[3] is a purely petrographical account of the principal rocks with short but useful descriptions. He distinguishes the two types of trachytic and leucitic rocks, and shows that the latter are later than the former. He also gives numerous mineralogical details of a series of ejected blocks, which are also described elsewhere by E. Artini.[4]

The other paper of this year is that of Deecke,[5] which constitutes one of his series of excellent articles on Italian geology. The first part of the article is devoted to a discussion of some of Verri's views and an exposition of his own regarding certain features of the volcano. The second part describes at length the ejected blocks found in the tuffs of Monte Vico, and the third describes various eruptive rocks collected by himself. An almost complete bibliography precedes the paper. Lacroix[6] also describes many of the ejected blocks and segregations from this region.

The best maps are those issued by the Italian government.

[1] RICCIARDI, Atti Acc. Gioen. Catania, XIX, 1884.
[2] BUCCA, Boll. Com. Geol. Ital., 1888, 57–63.
[3] MERCALLI, Rendic. Institut. Lomb., XXII, 1889.
[4] ARTINI, Atti Acc. dei Lincei, VI, 1889.
[5] DEECKE, Neu. Jahrb., B. Bd. VI, 205–240, 1889.
[6] LACROIX, Les Enclaves des Roches, Macon, 1893.

The southern part of the region is included in the completed Bracciano Sheet (Foglio 143, scale 1:100000) of the Geological Map of Italy.

Topography.—The Viterbo region lies a few kilometers southeast of Lake Bolsena, Viterbo being the chief town and best headquarters. It resembles in many respects the Bolsena region. East of Viterbo and in the northern part of the region lies the group of high hills known as the Monti Cimini, the early bulwark of the Etruscans against the Romans. The largest of these is Monte Cimino, a curving ridge running north and south, convex toward the east, its highest point 1053 meters above the sea and about 800 above the plateau of Viterbo. Connected with this and forming part of the same orographic mass are the lower Monti di Vitorchiano, Soriano, and La Pallanzana.

These, it may be said here, were formed by the older eruptions of the region. They are wholly built up of volcanic materials—lava streams and beds of tuff and a tuff-like rock. Stretching out around Monte Cimino to north, east, and west are lava streams and beds of trachytic tuff.

Immediately to the south of Monte Cimino, and southeast of Viterbo, is the most striking feature of the region—the great crater-ring of Monte Vico. This is almost circular in shape, its symmetry being broken by the projection of Monte Fogliano in the middle of its western side. Its greatest diameter—from north to south—is about five kilometers, and its widest part east and west is nearly as great.

The highest point of its rim is the summit of Monte Fogliano, 963 meters above sea level, the highest point on its northern edge being 896 meters, on the east 696, and on the south 607. It thus resembles the Bolsena, Latera, and other craters of Italy in having its southern rim the lowest. The inner slope is quite steep. Vom Rath estimates the average at 20°, which, judging from my own observations, seems much too low. In places, as on the east, and, according to vom Rath, on the south, it is quite precipitous. When not hidden by forests of oak trees it is seen that the walls are made up of beds of tuff with lava streams

and masses of lava blocks, tuff generally constituting the highest part of the ridge. The lavas of Monte Vico are predominantly leucitic, a few phonolites also having been observed.

The southern part of the interior of the crater is occupied by a lake whose surface is 507 meters above sea level. Its depth does not seem to have been ascertained, but it is apparently shallow. At the southeast corner an emissary has been cut for drainage purposes. Eventually the lake will probably give place to a plain, through drainage of its waters and filling up by denudation of the surrounding easily eroded tuff walls, as is the case at Agnano and elsewhere in Italy.

In the northern part of the crater there rises from the alluvial plain left by contraction of the lake from its original limits the so-called Monte Venere (Venus Mountain). This is a rounded hill with steep sides, whose summit is 317 meters above the lake level. The dense growth with which it is covered makes proper study of it difficult, but as far as I could judge it is a compact unstratified mass of eruptive rocks—a "dome" of leucite-trachyte. Part of the southeast flank is covered with pumiceous scoriæ, but elsewhere all such detrital material is lacking. Stoppani and Ricciardi mention a lava stream as flowing down its western side, which however I did not see, nor is it spoken of by Verri and Deecke.

From the ring wall of Vico the surface slopes gradually down on all sides at a low angle, except to the north where the Monti Cimini break the regularity. This surface is made up of yellow and gray tuffs containing leucitic, pumiceous, and some phonolitic blocks, as well as blocks of metamorphosed limestone, etc., such as are described by Deecke and Mercalli. Deep ravines—so characteristic of the surface topography of these regions—have been cut out by erosion, and diverge radially on all sides. Flank eruptions, which are so common at Bolsena, seem to be almost entirely wanting.

On the outskirts of the volcano the tuff and lava beds rest on late Eocene, and also in places on Pliocene deposits. Immediately to the south of the Vico crater lies the Bracciano region,

with its great crater lake, which will form the subject of the next paper.

It may also be noted that volcanic activity seems not yet entirely extinguished, since several hot springs occur in the neighborhood. The best known of these is that of Bulicame, which lies about 2^{km} to the west of Viterbo. This was probably known to the Romans, is mentioned by Dante, and is still flowing abundantly. The temperature of the water is 80°.[1] Verri also notes a few others near Ronciglione and Orte, and calls attention to the great deposits of travertine as evidence of the former abundance of mineral springs in the region.

We see from the above sketch that the structure of the region is somewhat different from that of the Bolsena region, since we find external to the great crater ring, and older than it, the Monti Cimini, and inside it the younger dome of Monte Venere.

A much more thorough study than has yet been attempted must be devoted to the region before all the problems it presents can be solved, but mention may here be made of the chief theories which have been proposed to account for some of its features. Since Verri's paper is the most detailed that we possess on the region it will not be out of place to quote briefly from his own résumé[2] of his views on the geological history and structure of the volcano.

According to him eruptions of fragmentary material broke out toward the close of the Pliocene period, and resulted in forming an island of trachytic tuff in the midst of the shallow sea. This was followed by eruptions of more solid material which formed Monte Cimino in the center of the island. After retreat of the sea consequent upon upheaval of the surface, which fractured the dome, trachytic lavas were poured out of the fissures thus made.

After this there was opened the Vico vent, both vents erupting simultaneously at first, though the eruptions of Monte Cimino soon ceased. With the opening of the Vico vent there

[1] DAUBENY, Volcanos. London, 1848, 160.

[2] VERRI, op. cit., 33.

appears a new mineral, leucite, which increases in abundance till toward the close it predominates largely over the other constituents. The eruptions of leucitic lavas were followed by those of lapilli, terminated by an explosion which threw out of the cone torrents of mud, burying the surrounding country for a distance of ten to fourteen kilometers.

The internal equilibrium of the cone was disturbed by the eruption of this vast amount of fragmentary material, and the greater part of the cone sank in, Monte Venere alone remaining above the waters of the lake—a fragment of the former summit which the action of the weather has reduced to a cone-shaped figure.

There are grave objections to be brought against certain points of this sketch, and Deecke devotes considerable space to arguments against two of them. He holds that Monte Cimino was not the result of a "domal" eruption of pasty trachytic magma followed by lava streams, as vom Rath and Verri believe, but that the mountain is part of what remains of the large crater ring of a true strato-volcano. The northwest wall of this has entirely disappeared and of the original cone only Monti Cimino, Valentano, La Pallanzana and one or two others are left. The crater was filled up, partly by its own eruptions and partly by the ejections from the neighboring Vico crater.

He agrees with Verri in thinking that the latest eruptions from the Cimino crater took place after those of Monte Vico had begun; but regards them as composed of "petrisco," which he considers with vom Rath to be a trachyte enclosing many leucites derived from the Vico lavas.

The arguments which he brings up against Verri's views that the crater lake of Vico is due to a sinking in of the top of the cone, and that Monte Venere is a half-sunken fragment, seem to me to be quite conclusive. They are so well given in his easily accessible paper that the reader is referred to it for a full presentation of them. He considers the crater a double one, due to powerful explosions, perhaps aided somewhat by sinking, and Monte Venere a true dome or *puy*—the last eruption of the

volcano. It may also be added that Stoppani combats Verri's views on these two points, as well as on the eruption of torrents of mud.

Though my own opportunities for observation were too limited to permit me to deal authoritatively with these problems, yet it may be of use to state briefly my own views. I am inclined to regard the Cimini eruptions as largely of a domal type, though lava streams and tuffs are more abundant than is usually the case with this type of volcano. Vom Rath's and Deecke's view as to the origin of the leucite phenocrysts in the "petrisco" I cannot agree with—a point which we shall have occasion to examine later on. I most decidedly concur with Deecke and Stoppani in considering the crater lake of Vico due chiefly to explosive eruptions, but think it probably a single crater, and that Monte Venere is a dome, representing the last eruption in the region. It is also well established that here, as at Bolsena, the leucitic lavas were later as a whole than the trachytic.

PETROGRAPHY.

We have to deal here, as in the Bolsena region, with two chief types of rocks, a trachytic and a leucitic. Petrographically the two regions are also alike in other more detailed features. The most important of these is the occurrence of a class of rocks intermediate between the trachytes and the andesites, which form a group of effusive rocks corresponding to some of Brögger's monzonites.

Vulsinite.—Of rocks corresponding to this type of intermediate effusive rocks characterized by the presence of both orthoclase and a basic plagioclase, there came to my notice only two occurrences, both being on the western border of the region. One is from Massa di San Sisto, about 7^{km} southwest of Viterbo on the road to Vetralla, where it forms a flow from the direction of Monte Fogliano cut through by the road. The upper part is visible here and there, though largely covered with travertine and leucitic tuffs. It is somewhat decomposed and fresh speci-

mens were hard to obtain. The other comes from near Vetralla 13[km] southwest of Viterbo, from a quarry whose exact location I could not ascertain. It may be from the same flow as the one first mentioned since the two closely resemble each other. The second is a light gray, harsh, typically trachytic rock. The groundmass is fine-grained and contains small biotite and augite phenocrysts, with many glassy tabular feldspars. The sp. gr. of this rock is 2.611 at 11°. The first is similar in character, but its color is a light reddish brown due to atmospheric decomposition. The feldspars are larger than in the other, and much resemble the sanidines of the well-known Drachenfels trachyte.

Under the microscope the two present much the same appearance. The phenocrysts are of orthoclase with fewer of labradorite, which contain few inclusions, the labradorite being included in the orthoclase; many well-formed phenocrysts of pale green diopside, including patches of brown glass and some magnetite; and some of brown biotite (especially abundant in the second rock), which is much corroded and "altered," though generally a core of unaltered substance remains.

The groundmass is holocrystalline and typically trachytic. Many small colorless or very pale green diopside prisms and anhedra, with not abundant magnetite grains, lie in a paste of alkali feldspar and fewer plagioclase laths showing flow structure. Between these laths in the second rock there is some alkali feldspar as cement, which is almost entirely wanting in the first. Stout apatite prisms with gray dusty inclusions are very common, and there are also a few small brown biotite flakes.

An analysis of the Vetralla specimen is given in No. 1 of Table II. Comparison will show the great resemblance between it and that of the typical vulsinite from Bolsena.[1] Its mineralogical composition is also almost identical, though labradorite takes the place of anorthite and is somewhat less abundant apparently. It may be said that the rock was thought to be rather a plagioclase-bearing trachyte till the analysis showed its essential identity with vulsinite.

[1] This JOURNAL, IV, 552, 1896.

Very similar, if not identical rocks from the western part of the region are described by vom Rath and Mercalli, and Verri also speaks of them. The "biotite-hypersthene-trachyte" from I Capuccini at Monte La Pallanzana described by Rosenbusch[1] also belongs here. He speaks of labradorite as abundant. A section of this rock which I obtained from Sturtz belongs apparently to the "peperino" described later. Bucca does not mention these rocks but describes a "trachyte" from Casaccia, at the southern end of Lake Vico. In this, however, he mentions olivine as visible megascopically, and a plagioclase as abundant both as phenocrysts and in the groundmass so that it is probably to be referred to the following group of rocks. This is also probably the same rock as that from near Ronciglione which Mercalli briefly describes as an "andesitic olivine-trachyte."

Ciminite.—The main mass of the Monti Cimini is made up of a peculiar rock, which occurs in streams and perhaps also as domal masses. In several places this rests on Pliocene clays, which have been more or less metamorphosed at the contact.[2]

The proper position of this rock in our classification has been uncertain almost from the first. Vom Rath calls it a trachyte, while Deecke refers it to the augite-andesites, though each acknowledges that the name chosen does not quite agree with the characters of the rock. Vom Rath indeed says that were it not for its sanidine content it would fit better into the augite-andesites; while Deecke remarks that it approaches basalt on the one hand through its content of olivine, and trachyte on the other by its structure and large sanidines. Bucca describes the rock from Madonna della Quercia (which, as Deecke says, belongs here) as a trachyte; though he mentions, without commenting on the peculiarity, that the phenocrysts are chiefly of abundant olivine and augite, with few of feldspar. He describes the rock from Fontana di Fiesole as a leucitic trachyte, but speaks vaguely of "distinguishing two parts in the rock, one composed essentially of leucite, the other forming a rock similar

[1] ROSENBUSCH, Mikr. Phys., II, 771, 1896.

[2] VOM RATH, op. cit., 299.

to those described [trachytes]." We have already seen that his "trachyte" from Casaccia probably belongs here. Mercalli also calls the Cimino rock an olivine-trachyte.

I was unfortunately unable to obtain specimens from the main mass of Monte Cimino, but those which I collected from the flows back of Madonna della Quercia and at Fontana di Fiesole[1] are of essentially the same type of rock. A specimen from below San Rocco in the Vico crater probably belongs to this latter center of eruption.

These rocks are all very compact, one of my specimens from Fontana di Fiesole alone showing a few elongated vesicles. Their color is light gray, that from the Vico crater being slightly greenish. In the fine-grained groundmass are scattered abundant small phenocrysts of pale yellow olivine, with small black augites, and fewer small glassy sanidines, the rock from Madonna della Quercia showing the most of these last. The Fiesole rock has a sp. gr. of 2.70 at 10° C.

Under the microscope they present much the same features, the only marked differences being in the greater or less development of feldspar and pyroxene in the groundmass. Feldspar phenocrysts are very rare in the slides and are seen to be both of orthoclase and plagioclase. No sections of the latter were found by which its exact character could be definitely determined, though it seems to be a rather basic labradorite. The feldspar phenocrysts are much corroded.

There is a great abundance of large and small phenocrysts of olivine, but this does not occur as a true groundmass constituent. They show the normal forms, more or less corroded, and are colorless and perfectly fresh in the interior. All show, however, a narrow, bright reddish-brown border, so frequent on olivine, and apparently of the same substance as that which has received the name of iddingsite.[2] This covers original crystalline, corrosion, and fracture surfaces alike, though here and there a small

[1] DEECKE (op. cit., 240) states that this flow probably belongs to the Bolsena center. He does not give the reasons for this view, and my own observations leave no doubt in my mind that it belongs to Monte Cimino.

[2] A. C. LAWSON, Bull. Dept. Geol., Univ. Cal., I, 31, 1893.

fracture is seen which does not show it. I am inclined to agree with Deecke in the view that some action of the magma is responsible for the existence of this border, since, as in his specimens, the perfect freshness of all the other minerals seems to exclude any appreciable meteorologic decomposition. The olivine is quite free from inclusions, except a few magnetite grains.

Diopside phenocrysts are also abundant, in fact more so than those of olivine. Only the largest show in the section a faint green color, the great majority being quite colorless. They are all well formed and automorphic, showing the usual planes with a stout prismatic habit, but the largest have suffered somewhat in transit and are more or less fractured. The extinction angle on *b* (010) reaches 45°, that of the interior being slightly higher than that of the border. In a few cases olivine crystals were noticed protruding into, and hence older than, the diopside. In the rock from Madonna della Quercia a single large crystal of brown biotite was seen, associated with large crystals of feldspar. It was much corroded, being reduced to a carious condition.

All these lie in a groundmass which shows both andesitic and trachytic features. Except in the rock from Vico crater, where diopside is comparatively rare, there is a typically andesitic "felt" of small diopside needles with many magnetite grains, the interstices being filled with feldspar. This is in the form of laths and also of "cement." The laths are both of orthoclase and of plagioclase in much smaller amount. Carlsbad twins are sometimes seen in the former, but twinning lamellæ are rare in the latter, which is chiefly to be distinguished by its oblique extinction and higher refractive index. Both are surrounded occasionally by narrow mantles of orientated alkali feldspar. The cement is entirely of alkali feldspar. Little or no apatite was noticed. Glass is present in small amount in the rock from Madonna della Quercia, but is almost entirely lacking in the other specimens.

The above description will have made evident the difficulty of classifying these rocks. As has already been said, the scarcity

of orthoclase phenocrysts, the abundance of plagioclase and presence of olivine, with the andesitic structure of the groundmass, would incline one to call them andesites, while the abundance of orthoclase in the groundmass inclines one towards the trachytes. At the same time the olivine is much more abundant than is usually found in an andesite, and the striking feature of the comparative rarity of the feldspars among the phenocrysts gives them a decidedly lamprophyric aspect.

Similar difficulties are met with when we come to examine the analyses of these rocks given below:

TABLE I.

	1	2	3	4
SiO_2	55.44	58.67	56.32	56.76
Al_2O_3	18.60	15.07	18.17	16.79
Fe_2O_3	2.09	——	2.23	2.07
FeO	4.48	8.35	6.47	6.95
MgO	4.75	2.97	2.84	1.63
CaO	6.76	8.07	5.33	6.01
Na_2O	1.79	3.36	1.80	2.43
K_2O	6.63	3.50	4.18	4.67
H_2O	0.25	0.82	2.15	2.44
TiO_2	0.16	——	——	——
P_2O_5	Trace	——	0.34	0.47
Sum.	100.75	100.81	99.83	100.22
Sp. Gr.		2.765	2.520	2.470

1. Fontana Fiesole, Viterbo. H. S. Washington anal.
2. West slope of Monte Cimino. Vom Rath, *op. cit.* 304.
3. Mont' Alfina. Bolsena Region. Ricciardi anal. Klein, *op. cit.* 7.
4. Sassara. Bolsena Region. Ricciardi anal. Klein, *op. cit.* 7.

Here we see that while as regards the silica, alumina, iron and lime they approach the andesites rather than the trachytes, yet that the potash is largely in excess of the soda and that the rock is far richer in total alkalies than is the case with the true andesites. The magnesia also is abnormally high.

We see, then, that this rock can be properly classed neither with the andesites nor the trachytes, but that, like the vulsinite previously described,[1] it occupies a position intermediate between

[1] This JOURNAL, IV, 547, 1896.

the two. Its position is, however, not exactly intermediate, since the large amount of magnesia and the presence of olivine throw it somewhat out of line. For these effusive rocks, characterized mineralogically by the presence of orthoclase with basic plagioclase, augite or diopside, and olivine, and chemically by rather low silica (53--58 per cent.), high magnesia and potash, high alkalis, with more potash than soda, and andesitic amounts of alumina, iron, and lime, I would propose the name of *ciminite*,[1] from their earliest known and most characteristic locality. It may be mentioned here that these rocks, as well as the vulsinites, show many analogies with the absarokite-banakite series from the Yellowstone Park described by Iddings.[2] Their relations with these, as well as with the other trachy-andesitic and the leucitic rocks of Italy will be discussed in the final paper.

"*Peperino*."—With the above may be described a rock concerning whose true character there has been much conflict of opinion. This is a soft, incoherent rock, easily cut with tools, which is much used for building purposes in the neighborhood. It goes locally by the name of "peperino," and was called by Brocchi "necrolite," on account of its use by the Etruscans for their sarcophagi and for the excavation of their tomb-chambers. It is quarried extensively at Bagnaia, to the east of Viterbo, where it rests on Pliocene beds and forms the oldest known product of the Ciminian eruptions.

This rock is called by vom Rath a trachyte, by Verri a trachytic tuff, by Mercalli a "quartz-bearing andesitic trachyte" or dacite, and by Deecke a mica-andesite. There is thus here, as in so many other instances, a great discrepancy among the various writers in regard to its character. The rock is too abundant, and too well known and much used in the region, and the descriptions tally too well to allow us to entertain the idea that the various observers are dealing with different materials. In this case I must decidedly agree with Verri in calling it a

[1] Pronounced chiminite.

[2] This JOURNAL, III, 935, 1895.

tuff, and consider it as derived from one of the peculiar trachy-andesites which are such a feature of this volcanic district.

I obtained my specimens fresh from the large quarries near Bagnaia, where it forms thick masses traversed by numerous fissures. Evidences of stratification were wanting. It is covered by looser beds of gray tuff containing, as pointed out by Verri and Deecke, many fragments of pumice and blocks of ciminite or a similar rock.

When first quarried it is very soft and friable, but hardens a great deal on exposure. It is rather coarse grained, made up of grains of feldspar, biotite, and augite, embedded in a finely granular paste. I could find none of the quartz mentioned by Mercalli. Its general color is a light yellowish gray, with spots and streaks of dark brown and gray, which give it somewhat the appearance of the well-known "piperno" of Pianura, near Naples.

Under the microscope it is seen to be composed of fragments of clear orthoclase, somewhat less abundant basic plagioclase (near labradorite) showing many twinning lamellæ, many brown and somewhat decomposed biotite crystals often frayed at the edges, and less numerous grayish green augites, all lying in a dusty, dirty, ill-defined groundmass. The fragmentary character of all the crystals is most marked, and there is lacking to all the constituents that definiteness of form and arrangement which characterizes true effusive rocks. The appearance is almost identical with that of many undoubted tuffs — so much so as to leave no doubt in my mind that the Bagnaia occurrences, at least, must be regarded as fragmental, and not effusive.

The only doubt cast upon this view is the presence in one slide of a large patch of obsidian. This shows similar, but much less broken, feldspar, biotite, and augite crystals, lying in a highly vitreous groundmass, which is made up of a clear, colorless isotropic base, flow structure being well brought out by abundant, damascene-like streaks of fine gray dust. These streaks curve about the large crystals, and also follow the line

of junction of the obsidian with the rest of the section. The contact line is rather vague, and close to the obsidian there are seen in the dusty groundmass some indications of a similar and parallel flow structure.

This patch might then be evidence in favor of the rock being a much decomposed and devitrified, highly vitreous, andesitic mica-trachyte, were it not for the wholly fragmentary condition of the crystals and the general similarity of the rock with other tuffs. The indications of flow structure seen in the dusty groundmass might be explained by the idea that they are due to the presence of part of the thin flake of obsidian extending beneath the tuff proper in the section. Such a flow structure is, however, clearly visible in such undoubted tuffs as those of Monte Epomeo on Ischia, and Monte Barbaro in the Phlegræan Fields and the obsidian-like patch may be due to secondary silicification. I may add that the view that the rock is a tuff accords better with the lack of contact metamorphism in the underlying Pliocene beds as commented on by Verri[1] and Deecke.[2]

Leucitic rocks.—These rocks, as we have seen, are confined apparently to the Vico center, though according to vom Rath and Deecke the latest ejections of the Cimino volcano were leucite-bearing.

There seems to be much less variety among the leucitic rocks of this region than was found among those of the Bolsena region. All the specimens which I collected may be referred to leucite-trachyte, and the same seems to be the case with those described by others, with a few exceptions to be noted presently.

Leucite-trachyte.[3]—This rock, which is known locally by the name of "*petrisco*," is very abundant in the region, forming flows and blocks in tuff around Monte Vico, as well as the domal Monte Venere. The flow occurrences are generally fresh, com-

[1] VERRI, op. cit., p. 26. [2] DEECKE, op. cit., p. 228.

[3] In Zirkel's sense, leucite phonolite of Rosenbusch. *Cf.* this JOURNAL, IV, 555, 1896.

pact, and extremely tough, while those forming ejected blocks in the tuff are so decomposed as to be very friable.

The flow specimens show a number of flat vesicles whose walls are smooth and occasionally coated with small crystals of nepheline, as was noticed by vom Rath. The groundmass is dark gray and very compact and aphanitic.

Through this are scattered leucite crystals in profusion, which make up in places over a third of the bulk of the rock and seldom fall below one-quarter, giving the rock a most characteristic appearance. The crystals are of good size, generally 0.5 to 1.0^{cm} in diameter, usually perfectly formed with sharp edges, but occasionally in fragments. While sometimes fresh and of the usual gray color and waxy luster (in one case yellowish through infiltration of ferruginous water), they are usually dull white, due to alteration. In the most altered specimens this kaolinization reduces them to a very friable and mealy condition. They include grains of augite and magnetite, which are irregularly arranged or clustered at the center. Apart from the leucites few phenocrysts are present, there being some sanidines and a few black augites.

In thin section the leucite-trachyte of Madonna di Lauro[1] near Vetralla, and that from a stream in the crater wall of Vico below San Rocco, which are typical of my Vico leucite rocks, present much the same characters. The large leucites are much cracked and exert little action on polarized light, the characteristic twinning being seen only in a few places. This is probably due to incipient or, as in the Vico rock, to evident alteration. There are not very abundant inclusions of augite, feldspar, magnetite, and glass. In the yellow leucites of one rock deposits of limonite are noted along all the crevices, while the leucite substance itself is quite colorless.

Feldspar phenocrysts are not uncommon, those of alkali feldspar being largely in the majority over those of plagioclase, which is a basic labradorite. Light brown glass inclusions are common, generally clustered toward the center. The pyroxene

[1] This is described by BUCCA, op. cit., 61.

phenocrysts are of a very pale green diopside and are highly automorphic. Some show evidences of fracture and corrosion, while a few have at the ends a late fringing growth of small diopside needles arranged parallel to the vertical axis. Except for a few large magnetite grains other phenocrysts are wanting.

The groundmass is decidedly andesitic in structure. Small stout needles of diopside, and of the brown pleochroic barkevikite-like hornblende seen in Bolsena leucite-tephrites,[1] many small alkali feldspars and a few plagioclase laths, and many well-shaped magnetites lie in a colorless glass base with absolutely no evidence of flow structure. Here and there are small round spots of a colorless substance whose inclusions and analogies with similar forms in others of these Italian rocks show them to be leucite, though their double refraction is scarcely visible. Apatite needles are also present in all the specimens. The colorless base is isotropic and seems to be entirely of glass. No nepheline could be detected with certainty. In one rock some alkali feldspar flakes are also present, and the glass in many places is of a light brown color.

Analyses of two of these rocks are given in Table II, Nos. 4 and 5. They resemble each other fairly well though 5 is lower in SiO_2 and Al_2O_3 and higher in iron oxides and lime. The analysis of the groundmass of a leucite-trachyte from the Vico Crater, by Ricciardi (No. 6), shows somewhat lower silica, extremely high alumina, considerably more lime, and less iron and alkalis. These are what we would expect to find, except the very high alumina, and perhaps the lower iron.

A few specimens of much decomposed petrisco from blocks in the latest tuff also deserve mention. They are so friable as to crumble readily between the fingers, rendering it difficult to obtain good specimens. The groundmass is black or brownish-black and very fine grained. This is thickly peppered with small and large leucites, with a few small sanidines, which stand out prominently against the dark background. The leucites in general are perfect and well formed, though some fragments

[1] Cf. this JOURNAL, IV, 562, 1896.

occur. They are all of a dull pure white and extremely friable —due to a process of kaolinization. A few small augite phenocrysts are also visible.

Under the microscope they resemble somewhat those just described, the differences being largely due to decomposition. The large leucites, many of which have fallen out, are of a pale yellow color and quite isotropic. The original leucite substance has given place to a peculiar alteration product which here and there is subfibrous in structure, but more often resembles a gum. It is filled with perlitic cracks which split it up into spheroidal masses.

The groundmass is very fine-grained and rather hyalopilitic in structure, formed of a felt of small diopside and alkali feldspar laths with magnetite grains, lying in a base either of brownish glass or glass with flakes of orthoclase. Scattered through it are small leucites, from 0.02 to 0.07^{mm}, which, though perfectly isotropic, leave absolutely no doubt as to their real nature, since they show the characteristic isolated inclusions, and often the still more characteristic skeleton forms previously described.

The leucites in these rocks, as well as in some of the flows, are supposed by vom Rath, Bucca, and Deecke to be inclosures derived from leucitic lavas of Monte Vico which were caught up during the eruption of Ciminian "trachytes." This view is based on the supposed facts that the leucite is always phenocrystic, is always or generally in fragments, is always kaolinized, and also on the chemical composition of the rock.

With this theory I cannot agree. In the first place my own observations lead me to agree with Verri (p. 29) in thinking that the greater part, if not all, of this petrisco-bearing tuff was derived from the Vico crater. Furthermore, the leucite, while chiefly present as phenocrysts, also occurs abundantly in the groundmass as we have seen. The fragmentary character of the large leucites did not appear to me to be nearly as universal as stated by the above writers; and even were it so it would not be surprising when the peculiar molecular condition of the mineral is

considered.[1] In all the occurrences which I saw and in all my hand-specimens the perfection of form of the tetragonal trisoctahedron is very striking, and furthermore the abundance of the leucites is too great to countenance the idea of their accidental presence. The state of alteration does not seem to me to have any bearing on the case, since this is dependent on surface conditions and would go on the same no matter what the origin of the crystals. The argument may rest on the ground that a trachytic magma would be at a higher temperature than a leucitic magma, but this idea is not expressed by either of the above writers. Vom Rath's analysis of petrisco is given in Table II (No. 6), and while it differs considerably from those of similar rocks from the Bolsena and other regions in containing less lime and magnesia and more silica and alkalis, yet it can be closely paralleled by analyses of similar rocks containing undoubtedly primary leucites to be described later.

The rock composing the dome of Monte Venere, which forms the last eruption of the region, is also a leucite-trachyte, but of a somewhat different type. The groundmass is very compact with only a few small vesicles, and the color is light gray. It is very tough under the hammer—a characteristic of most of the leucite rocks of all these regions. The leucite phenocrysts are neither as numerous nor do they stand out as prominently as in the preceding types, being small, quite fresh and glassy, and of a pale grayish white color. There is an abundance of very small phenocrysts of dark pyroxene and some small scales of biotite. The sp. gr. of this rock is 2.609 at 10° C.

Under the microscope leucite is seen to be a much more generally distributed constituent than in the preceding, or than the megascopical examination would lead us to suppose. It runs down from the larger phenocrysts to very small crystals of the groundmass, of which it forms a very large part. It seldom shows definite crystal boundaries; and inclusions, as well as double refraction, are rare.

Feldspar phenocrysts are common, and plagioclase is more

[1] Cf. ROSENBUSCH: Mikr. Phys., I, 311, 1892, and II, 826, 1896.

abundant than in the preceding rocks, which led Mercalli to call it a leucite-tephrite. They all carry very narrow irregular mantles of orientated alkali feldspar. The pyroxene is quite similar to those already described, but the green color is deeper and the augite molecule evidently surpasses that of the diopside. It frequently carries inclusions of apatite needles.

The most prominent difference in these Monte Venere rocks is the presence of quite numerous phenocrysts of brown biotite, which show strong pleochroism. They are quite fresh over the greater part of their area, but carry borders of large and loosely coherent augite and magnetite grains. A few are entirely altered and only represented by clusters of these grains showing roughly the original form. The groundmass is largely made up of small round leucite anhedra. Between these lie many laths and flakes of alkali feldspar, fewer augite microlites, and many magnetite grains, all of which are imbedded in a colorless glass base with no apparent flow structure. There is no evidence of the presence of nepheline. An analysis of this rock is given in Table II, No. 7.

The above descriptions embrace all the leucitic rocks collected by myself, but a few of a different character are described by other observers. Deecke mentions leucite-basanite as occurring on the south shore of Lake Vico, as well as among the lapilli of Monte Venere; and Mercalli notes a similar rock from San Martino, between Viterbo and Monte Fogliano. Bucca also describes an olivine-bearing leucite-tephrite from Capo d'Acqua, near Vetralla. Mercalli speaks of leucite-tephrites as occurring in several places, but his brief descriptions leave it uncertain whether leucite-trachytes are not intended. He also mentions a leucitic-phonolite as occurring in erratic blocks in the tuff which carries the phonolites described later. Deecke describes a number of leucite-phonolites (leucitophyrs) from Piazza, on the southeast shore of Lake Vico, from below San Rocco, and from Borghetto near Civita Castellana, east of the volcano. This last probably belongs to a flank eruption. They closely resemble the leucite-trachyte first described, except that they carry

nepheline in the groundmass. The apparently total absence of leucitites, which is commented on by Mercalli, is a most striking fact, and in great contrast to the adjacent centers of Bolsena and Bracciano.

Phonolites.—The presence of these rocks would seem to be an exception to the statement on a previous page that the Viterbo rocks can be divided into only two classes. They occupy, in fact, an exceptional position, occurring only as blocks in the last tuff ejected by Monte Vico and in a couple of dikes observed by Deecke. Their total amount is moreover very small, quite subordinate to those of the ciminites and leucite-trachytes. Of these rocks I collected three specimens. One is from a loose block in the yellow tuff west of Viterbo, another from a block in the tuff at the Posta on the north edge of the Vico crater. They are very compact and tough, with no great tendency to break into slabs under the hammer. In the aphanitic, greenish gray, slightly greasy groundmass are a few small glassy sanidine phenocrysts, stained light brown in places, still fewer small dark pyroxenes, and here and there a bright blue speck of haüyne. The sp. gr. is 2.509 at 10°.

Under the microscope it presents a normal phonolitic structure of Rosenbusch's nephelinitoid type. The large orthoclase phenocrysts are clear and free from inclusions, though a little brown limonitic material lies along the cracks. They are tabular parallel to the clinopinacoid, show commonly Carlsbad twinning, and often have corroded outlines. Mantles of orientated alkali feldspar are common. The rather rare augite phenocrysts are well formed and of an olive green color, and quite strongly pleochroic. Since the axis of greatest elasticity **a** makes an angle of about 30° with the vertical axis they belong to the ægirine-augites.

Rather large haüynes are quite abundant and frequently show octahedral and cubic planes. They are generally colorless in the interior and bright blue toward the edge, though sometimes blue all over, or brown inside and blue out. They show the peculiar inclusions arranged in fine parallel straight lines, often

forming systems at right angles. These are best developed at the borders of the crystal. Haüyne is occasionally seen included in, and hence older than, large orthoclase phenocrysts.

The groundmass is holocrystalline and composed of small ægirine prisms and alkali feldspar laths scattered through a paste of nepheline, which occasionally shows characteristic crystal boundaries. The powdered rock gelatinizes abundantly with acids, the solution furnishing cubes of sodium chloride, and staining of the slides renders the identity of the nepheline certain. There are also present some small magnetite grains, quite abundant apatite needles, and a number of bright colorless highly refracting grains and crystals of titanite, which often show the characteristic pyramidal forms and rhombic sections. No leucite was seen.

An analysis of this rock by the writer is given in Table II, No. 9, the alkali percentages being the means of $Na_2O = 4.86$ and 4.90, and $K_2O = 9.21$ and 9.06, so that their relative amounts are beyond question. The analysis by vom Rath of his "phonolitic trachyte" is shown by No. 10. It would seem possible that there has been a transposition of the figures for the alkalis in vom Rath's paper.[1] This phonolite is then noteworthy for its very high potash content, which explains the large amount of orthoclase seen in thin sections. The amount of lime being very small and having been exhausted in the formation of diopside, and the potash having taken up most of the silica to form orthoclase the soda left from the ægirine went chiefly into nepheline rather than into albite.

Mercalli describes the above rocks under the name of "haüynitic sanidinite," but does not mention nepheline, though he says that they have the megascopic characters of phonolite. The description of the rock which vom Rath (p. 580) calls a phonolite-like trachyte from the Ciminian Mountains answers in every way to those just described, except that it is said by him to contain leucite and that it is quarried. The exact locality is not

[1] The discrepancy between the analysis and the description of the rock is commented on by ZIRKEL (Lehrbuch, II, 467).

given. He does not mention nepheline but speaks of a mineral in the groundmass which "may be sanidine," and states that the rock gelatinizes abundantly with HCl. The analysis (No. 9, Table II) is hardly that of a leucite-phonolite, so that the rock may be classed as a phonolite with accessory leucite.

A phonolite of a somewhat different character is from a lava stream in the steep inner wall of Monte Vico, north of Monte Venere. This is a compact fine-grained gray rock, highly vesicular in structure, with a few small nepheline crystals visible on the walls of the vesicles. Glassy twinned tabular sanidines are abundant. Under the microscope it is seen to belong rather to the trachytoid type of Rosenbusch. The orthoclase phenocrysts are similar to those of the preceding specimens, but the rare pyroxene phenocrysts are rather augite proper than ægirine-augite. No haüyne is to be seen, but shreds of much altered brown biotite are found here and there. The groundmass is quite trachytic in character, the ægirine needles being less abundant and alkali feldspar laths much more so than in the other type, with marked flow structure. These, with considerable magnetite and some very small titanite grains, lie in a holocrystalline paste of what is apparently a mixture of orthoclase and nepheline. The former is in somewhat large flakes, and the latter distinguishable by its very weak double refraction and its behavior with acids.

Deecke describes some true phonolites which form two dikes in the eastern crater wall of Monte Vico. They correspond very closely to those described above. It is worthy of note that phonolite also occurs as a dike at Le Braidi on the eastern flank of Monte Vulture,[1] but has not been observed among the other products of this volcano.

Analyses.—In Table II are given the most reliable of the few analyses of the rocks of this region. No. 5 was made for me by Dr. A. Röhrig of Leipzig. No. 2 was made in the Mineralogical-Petrographical Laboratory of Yale University under the direction of Professor L. V. Pirsson, to whom I take the opportunity

[1] DEECKE, New Jahrb., B. Bd. VII, 602, 1891.

of returning my sincere thanks for his invaluable aid and advice. Nos. 7 and 9 were made in my own laboratory. The discussion of these analyses will be reserved for the final paper.

TABLE II.

	1	2	3	4	5	6	7	8	9	10
SiO_2	57.32	55.44	58.67	59.51	55.26	54.41	55.21	55.08	59.24	60.18
Al_2O_3	19.85	18.60	15.07	18.89	16.36	22.91	19.81	18.31	18.97	18.70
Fe_2O_3	2.21	2.09	....	....	5.26	1.45	2.69	1.67	3.30	....
FeO	2.35	4.48	8.35	5.26	2.90	4.67	2.86	7.06	1.20	3.44
MgO.....	1.60	4.75	2.97	1.50	1.14	1.54	1.68	2.18	0.12	0.32
CaO.....	3.82	6.76	8.07	1.90	3.90	6.73	4.61	5.79	2.06	2.80
Na_2O	3.22	1.79	3.36	4.99	4.08	[1]1.64	3.13	[1]1.34	4.87	9.67
K_2O	9.15	6.63	3.50	7.25	8.82	5.36	8.45	6.59	9.14	4.18
H_2O	0.57	0.25	0.82	0.56	1.20	1.53	0.99	2.19	0.86	0.33
TiO_2	....	0.16	....	....	0.36	....	Trace	....	0.48	....
P_2O_5	....	Trace	....	....	....	Trace	....	Trace	....	....
Cl.....	....		....	0.19	....	....	....	....	....	0.14
SO_3	....	....	....	....	....	....	....	....	0.10	0.19
	100.09	100.75	100.81	100.05	99.28	100.24	99.43	100.21	100.34	99.95
Sp. Gr.....	2.611	2.700	2.765	2.603	.....	.....	2.609	.....	2.509	2.522

1. Vulsinite, near Vetralla, H. S. Washington anal.
2. Ciminite, Fontana Fiesole, Viterbo, H. S. Washington anal.
3. Ciminite, West Slope of Monte Cimino, vom Rath, *op. cit.*, 304.
4. Leucite-Trachyte, "Petrisco," Viterbo, vom Rath, *op. cit.*, 298.
5. Leucite-Trachyte, Madonna di Lauro, Vetralla, A. Röhrig anal.
6. Leucite-Trachyte, *Groundmass*, Vico Crater, Ricciardi, *op. cit.*
7. Leucite-Trachyte, Monte Venere, H. S. Washington anal.
8. Leucite-Trachyte, *Groundmass*, Monte Venere, Ricciardi, *op. cit.*
9. Phonolite, block in Tuff, west of Viterbo, H. S. Washington anal.
10. Phonolite, Monti Cimini, vom Rath, *op. cit.*, 581.

HENRY S. WASHINGTON

[1] Trace of Li_2O.

STUDIES FOR STUDENTS.

THE PRINCIPLES OF ROCK WEATHERING.

(*Concluded.*)

(*c*) MECHANICAL ACTION OF WATER AND OF ICE.

ASIDE from its solvent capacity, water acts as a powerful erosive agent, as well as an agent for the transportation of the eroded materials. It is only its erosive power that need concern us here, though as we shall see this is to a considerable extent dependent upon its power of transportation. Every raindrop beating down upon a surface already sorely tried by heat and frost serves to detach the partially loosened granules, and, catching them up in the temporary rivulets, carries them to the more permanent rills to be spread out over the valley bottoms, or perhaps if the slopes be steep and the current accordingly strong to the rivers and thence to the sea. The amount of detrital matter thus mechanically removed from the hills and spread out over valley and sea bottoms quite exceeds our comprehension, but it is estimated that at the rate the Mississippi River is now doing its work the entire American continent might be reduced to sea level within a period of four and one half million years. The Appalachian Mountain system has already, through this cause, lost more material than the entire mass of that which now remains. But the rivers, like the winds and glaciers, in virtue of this load of sand they bear, become themselves converted into agents of erosion, filing away upon their rocky beds, undermining their banks and continually wearing away the land by their ceaseless activity. The pot-holes in the bed of a stream, formed by the constant swirl of sand and gravel in an eddy, furnish on a small scale striking illustrations of this cutting power, while the rocky canyons of the Colorado of the west, where thousands of feet of horizontal strata have been cut through as with a file,

show the same thing on a scale so gigantic as to be at first scarce comprehensible.[1] An item of no insignificant importance to be considered here, is the possibility, indeed probability, of an incidental chemical decomposition taking place during this abrasive action.

Daubree has shown[2] that when feldspathic fragments were submitted to artificial trituration in a revolving cylinder containing water, a decomposition was effected whereby the alkalies were liberated in very appreciable amounts. He found further that the principle product of mutual attrition of feldspathic fragments was an impalpable mud (limon) of such tenuity as to remain for many days in suspension, and which on desiccation became so hard as to be broken only with the aid of a hammer, resembling in many respects the argillites of the Coal Measures, but differing in that it carried a high percentage of alkalies. Granitic rocks thus treated yielded angular fragments of quartz and very minute shreds of mica, while the feldspars ultimately quite disappeared in the form of the impalpable mud above mentioned. It was noted that after a certain degree of fineness had been reached further rounding of the particles ceased, owing to the buoyant action of the water, which, in the form of a thin film between adjacent particles, acted as a cushion and prevented actual contact to the extent necessary for mutual abrasion. It is to a similar action on the part of sea water that Shaler[3] would attribute the lasting qualities of the sand grains upon our sea beaches. Indeed the conditions of Daubree's experiments as a whole were not so different from those existing in nature that we need hesitate to conclude that similar action, both chemical and physical, may be going on wherever abrasion takes place in the presence of continual moisture, as in the bed of a river or glacier.

The hammering action of the waves upon the seacoast exert

[1] CAPTAIN C. E. DUTTON has estimated (Tertiary History of the Grand Canyon of Colorado) that from over an area of 13,000 to 15,000 square miles drained by the Colorado River an average thickness of 10,000 feet of strata have been removed.

[2] Geologie Experimentale, p. 268.

[3] Bull. Geol. Soc. of America, Vol. V, p. 208.

a powerful erosive action, particularly upon particles of rock of such size as to be lifted or moved by wave action, but too heavy to be protected from attrition by the thin film of water above alluded to. Shaler's observation[1] at Cape Ann were to the effect that ordinary granitic paving blocks (weighing perhaps twenty pounds) were, when exposed to surf action worn in the course of a year into spheroidal forms such as to indicate an average loss of more than an inch from their peripheries. Experiments made with fragments of hard-burned brick showed that in the course of a year they would be reduced fully one-half their bulk. Even the crystallization of the salt thrown up by wave action and absorbed into the pores of rocks[2] serves in its way the purposes of disintegration.

The action of freezing water and of ice.—The action of dry heat and cold in disintegrating rocks has already been described. The effects of such temperature changes upon stone of ordinary dryness are however slight in comparison with the destructive agencies of freezing temperatures upon stones saturated with moisture. The expansive force of water passing from the liquid to the solid state has been graphically described as equal to the weight of a column of ice a mile high (about 150 tons to the square foot). Otherwise expressed, one hundred volumes of water expand, on freezing, to form one hundred and nine volumes of ice. Provided then sufficient water be contained within the pores of a stone, it is easy to understand that the results of freezing must be disastrous. That stones as they lie in the ground do contain moisture, often in no inconsiderable amounts, is a fact well-known and well-recognized by all those engaged in quarrying operations, and indeed no mineral substance is absolutely impervious to it. The amount contained naturally varies with the nature of the mineral constituents and their state of aggregation. According to various authorities granite may con-

[1] Bull. Geol. Soc. of America, Vol. V, p. 208.

[2] According to DANA (Wilkes Exploring Expedition. Geology, p. 529) the sandstones along the coast of Sydney, Australia, are subjected to a mechanical disintegration through the crystallization of the salt which is absorbed from the saline spray of the ocean waves.

tain some 0.37 per cent. by weight; chalk, 20 per cent.; ordinary compact limestone, 0.5 per cent. to 5 per cent.; marble, about 0.30 per cent., and sandstones varying amounts up to 10 or 12 per cent., while clay may contain nearly one-fourth its weight. At and near the surface the amount, particularly after rains, may be very considerably increased. This water is largely interstitial —the *quarry water*, as it is sometimes called. In addition to this the quartz, particularly of granitic rocks, almost universally contains innumerable minute cavities partially filled with water, and which are in extreme cases so abundant as to make up, according to Sorby, at least 5 per cent. of the whole volume of the mineral.

That the passage of this included moisture from the liquid to the solid state may be attended with results disastrous to the stone is self-evident, though the rate of disintegration may be so slow under favorable circumstances as to be scarce noticeable. Freezing of the absorbed water is one of the most fruitful sources of disintegration in stones confined in the walls of a building, and even in the quarry bed it is by no means uncommon to have the material so injured as to render it worthless. However slight may be the effects of a single freezing upon a rock, constant repetition of the process cannot fail to open up new rifts, and still further widen those already in existence, allowing further penetration of water, which freezes in its turn, and exerts a chemical action as well. So year in and year out, through winter's cold and summer's heat, the work goes on until the massive rock becomes loose sand to be caught up by winds or temporary rivulets and spread broadcast over the land. In some instances, it may be, the rock is of sufficiently uniform texture to be affected in all its mass alike. More commonly, however, it is traversed by numerous veins, joints or other lines of weakness along which the rifting power is first made manifest. Naturally disintegration of this kind is confined to frigid and temperate latitudes. As bearing upon the extreme rapidity with which such disintegration may take place, I quote the following from a letter of Dr. L. Stejneger, of the Smithsonian Institution, who passed several months among the islands of Bering Sea:

"In September, 1882, I visited Tolstoi Mys, a precipitous cliff near the southeastern extremity of Bering Island. At the foot of it I found large masses of rock and stone which had evidently fallen down during the year. Most of them were considerably more than six feet in diameter, and showed no trace of disintegration. The following spring, April 1883, when I revisited the place I found that the rocks had split up into innumerable fragments, cube-shaped, sharp-edged, and of a very uniform size, about two inches. They had not yet fallen to pieces, the rocks still retaining their original shape. I may remark, however, that the weather was still freezing when I was there. The winter was not one of great severity and several thawing spells broke its continuity. These cubic fragments did not seem to split up any further, for everywhere on the islands where the rock consisted of the coarse sandstone, as in this place, the talus consisted of these sharp-edged stones."

Ice acts as an agent of disintegration in still other ways than that mentioned above. Glaciers and their attendant phenomena have, however, been so thoroughly discussed of late in the columns of this and allied journals that my remarks upon the subject may here be very brief. The moving glacier transports more or less rock débris fallen upon it from the hills on either hand or picked from the surfaces over which it flows. Those materials which are carried upon the surface, or frozen in the upper portions of its mass, may be but transported to the lower levels, where, the temperature being sufficient, the ice is melted and deposits its load in the form of a moraine. Those which become frozen into the ice-sheet at its under surface are crowded, as the glacier moves onward with all the weight of the overlying mass and all the resistless energy of the ice behind, over the surface of the underlying rocks. In virtue of this material, this sand, gravel and bowlder aggregate, the glaciers become converted into what we may compare to extremely coarse files, to tear away the rocks over which they pass and grind and crush them into detritus of varying degrees of fineness. The small streams which originate from the melting of these glaciers become, hence, not

infrequently charged to the point of turbidity with the fine silt-like detritus ground from the ledges and in part from the bowlders themselves. This feature has been so frequently noted in geological text-books, as to need no farther mention here.

(*d*) *Action of plants and animals.*—Both plants and animals aid to some extent in the work of rock degeneration.

The lowest forms of plant life, the lichens and mosses growing upon the hard, bare face of rocky ledges, send their minute rootlets downward into every crack and crevice, seeking not merely foothold but food as well.

Slight as is the action it aids in disintegration. The plants die, and others grow upon their ruins. There accumulates thus, it may be with extreme slowness, a thin film of humus, which serves not merely to retain the moisture of rains but also to bring the rock under the influence of chemical action. As time goes on, sufficient soil gathers for other, larger and higher types of life, which exert still more potent influences. It may be the rock is in a jointed condition. Into these joints each herb, shrub, or sapling pushes down its roots, which in simple virtue of their gain in bulk, day by day, serve to enlarge the rifts and furnish thereby more ready access for water, and the wash of rains to still further augment disintegration. This phase of root action is often well shown in walls of ancient masonry, either of brick or stone, where they greatly accelerate the usual rate of destruction. The depth to which such roots may penetrate has often been noted,[1] varying, as is to be expected with the nature of the soil. In the limestone caverns of the southern states the writer has often noted the number of long thread-like rootlets which have found their way through rifts in the rocky roof, so fine as to be almost imperceptible. In this, as in others of nature's processes, we must remember that nothing is done in haste. With boundless time, and resources without limit, Dame Nature works out her results at her own time and by her own methods.

[1] Aughey has found roots of the buffalo berry (*Sheperdia argophylla*) penetrating the loess soils of Nebraska to the depth of fifty feet.

Aside from this physical action plants promote disintegration by keeping the surface of rocks continually moist, and through their decay by supplying the complex series of compounds commonly called humic, ulmic, crenic and apocrenic acids to which reference has already been made. These act both as deoxidizing and solution agents.

"There is reason to believe that in the decomposition effected by meteoric waters and usually attributed mainly to carbonic acid, the initial stages of attack are due to the powerful solvent capacities of the humus acids. Owing, however, to the facility with which these acids pass into higher states of oxidation, it is chiefly as carbonates that the results of their action are carried down into deeper parts of the crust or brought up to the surface. Although CO_2 is no doubt the final condition into which these unstable organic acids pass, yet during their existence they attack not merely alkalies and alkaline earth, but even dissolve silica."[1]

It is stated by Storer that "on the tops of the higher hills of New Hampshire, and on the coast of Maine also, a cold, sour black earth will often he noticed at the surface of the ground, immediately beneath which is sometimes a layer of remarkably white earth. The whiteness is due to the solvent action of acids that soak out from the black humus, and which leach out from the underlying clay and sand the oxides of iron that formerly colored them, leaving only the insoluble pure clay or sand."

H. Carrington Bolton has shown that very many minerals are decomposed by the action of cold citric acid for a more or less prolonged period, the zeolites and other hydrous silicates being especially susceptible. Such tests have a peculiar significance when we consider that the roots of growing plants secrete an acid sap

[1] GEIKIE, Text-book of Geology, 3d ed., p. 472. The writer was shown not long since, a very practical illustration of the remarkable corrosive power of organic acids. A highly ornate French clock with case of black marble was packed for storage in excelsior which was a trifle damp. The clock remained in storage from the last of May until about the first of October. When the packing material was removed, the marble was found to be so corroded as to need rehoning and polishing. The roughness could be easily felt by passing the finger over the surface, and long lusterless lines indicating the contact of excelsior fibers traversed the surface in every direction.

which by actual experiment has been found capable of etching marble. The exact nature of this acid is not accurately known, but it is considered probable that in the rootlets of each species of plant there exist a considerable variety of organic acids.[1]

But the effects of plant growth are not necessarily always destructive; they may exert a conservative or even protective action. In glaciated regions it is often the case that the striated and polished surfaces of the rocks have been preserved only where protected from the disintegrating action of the sun and atmosphere by a thin layer of turf or moss. As a general rule, however, the manifest action of plant growth is to accelerate chemical decomposition, through keeping the surfaces continually moist, and to retard erosion.

Action of bacteria.—The researches of A. Müntz,[2] Widogradsky, Schlösing and others have shown that bacteria may exercise a very important influence in promoting rock disintegration and decomposition. Their influence in promoting nitrification has been already alluded to. It would appear that while these organisms may secrete and utilize for their sustenance the carbon from the carbonic acid of the atmosphere, as do plants of a higher order, they may also assimilate the carbonate of ammonium, forming from it organic matter and setting free nitric acid. Being of microscopic proportions these organisms penetrate into every little cleft or crevice produced by atmospheric agencies, and throughout long periods of time produce results of no inconsiderable geological significance. The depth below the surface at which such may thrive is presumably but slight, and their period of activity limited to the summer months. They have been found on rocks of widely different character—granites, gneisses, schists, limestones, sandstones and volcanic rocks—and on high mountain peaks as well as on lower levels. The Pic Pourri, or Rotten Peak, in the Lower Pyrenees of southwest-

[1] See Application of Organic Acids to the Examination of Minerals. H. CARRINGTON BOLTON, Proc. Am. Assoc. for the Advancement of Science XXXI, 1883. Also Available Mineral Plant Food in Soils. B. DYER, Jour. Chem. Society, March 1894.

[2] COMPTES RENDUS DE L., Academie des Sciences, CX, 1890, p. 1370.

ern France is composed of friable and superficially decomposed calcareous schists throughout the whole mass of which are found the nitrifying bacteria which are believed to have been instrumental in promoting its characteristic decompositions. The organism acts even upon the most minute fragments, reducing them continually to smaller and smaller sizes. Each fragment loosened from the parent mass is found coated with a film of organic matter thus produced, and the accumulation begun by these apparently insignificant forces is added to by residues of plants of a higher order which come in as soon as food and foothold are provided.

Mr. J. E. Mills,[1] as already noted, lays considerable stress on the decomposing effects of the carbonic acid gas which the ants are "continually pouring" into the upper layers of decomposed material. What the original source of this carbonic acid may have been is not stated, but the natural assumption is that it arises from the decomposing organic matter in their burrows.

Certain species of ants, locally known as saubas, or sauvas, live, according to Branner,[2] in enormous colonies, burrowing in the earth where they excavate chambers with galleries that radiate and anastomose in every direction, and into which they carry great quantities of leaves. Certain species of termites, the *white ants* of Brazil, are also active promoters in bringing about changes in the structure of the soil, and incidentally accelerating decomposition. The organic matter carried by these creatures into the ground, there to decompose, furnishes organic acids to promote further decay in the material close at hand, and by its downward percolation to attack the still firm rocks at greater depths. Indeed these numerous channels, through affording easy access of air, and surface waters with all their absorbed gases or alkaline salts, may serve indirectly a geological purpose scarcely inferior to that of the joints in massive rocks.

The mechanical agency which has already been referred to as instrumental in bringing about a certain amount of decom-

[1] Am. Geologist, June 1889, p. 351.

[2] Bull. Geol. Soc. of Am., Vol. VII, 1895.

position in silicate minerals, is greatly augmented when such trituration takes place in connection with organic matter. J. Y. Buchanan has shown[1] that the mud of sea bottoms is being continually passed and repassed through the alimentary canals of marine animals, and that in so doing the mineral matter not merely undergoes a slight amount of comminution and consequent decomposition, but a chemical reduction takes place whereby existing sulphates are converted into sulphides. Such sulphides and the metallic constituents of the silicates and other compounds, particularly those of iron and manganese, would on exposure to sea water become converted into oxides. It is through such agencies that he would account for the presence of sulphur in marine muds, and the variations in color, from shades of red or brown to blue and gray, in the former the iron occurring as oxides, while in the latter it exists as a sulphide. Of course either form may be more or less permanent according as the mud may be devoid of animal life, or protected from oxidizing influences.

3. ANALYSES OF FRESH AND DECOMPOSED ROCKS.

Let us now take into consideration a few common rock types which have undergone a process of degeneration through weathering, and by means of analyses ascertain, so far as possible, the chemical and physical changes which have taken place. In the table below are given, in each case, the results of analyses of fresh and decomposed materials, and the calculated percentage loss of constituents, both as relates to the entire rock, and to the individual constituents. In making these calculations it has been necessary to assume that one of the constituents remains practically constant, in order that it may serve as a basis of comparison. That constituent which has been shown by a large series of analyses to be most constant is, among siliceous crystalline rocks, the alumina, though sometimes it is the iron. Among calcareous rocks it is the silica. In any case,

[1] On the Occurrence of Sulphur in Marine Muds. Proc. Royal Soc. of Edinburgh, 1890–1.

by selecting as a standard of comparison that of the constituents which has suffered the least through the leaching action of water during the process of degeneration, we may gain by calculations which it is unnecessary to repeat here a series of numbers showing the loss of constituents as given below, and which may safely be accepted as rather under than above the actual figures.

ANALYSES OF FRESH AND DECOMPOSED GNEISS.

Constituents	1 Fresh gneiss	2 Decomposed gneiss	3 Loss	4 Percentage amount of each constituent saved	5 Percentage amount of each constituent lost
Silica.....(SiO_2)	60.69	45.31	31.90	47.55	52.45
Alumina .....(Al_2O_3)	16.89	26.55	0.00	100.00	0.00
Iron sesquioxide..(Fe_2O_3)	9.06	12.18	1.30	85.65	14.35
Lime .....(CaO)	4.44	trace	4.44	0.00	100.00
Magnesia .....(MgO)	1.06	0.40	0.80	25.30	74.70
Potash .....(K_2O)	4.25	1.10	3.55	16.48	83.52
Soda .....(Na_2O)	2.82	0.22	2.68	4.97	95.03
Phosphoric acid ...(P_2O_5)	0.25	0.47	0.00	100.00	0.00
Ignition ....(H_2O and C)	0.62	13.75	0.00	100.00	0.00
Total loss			44.67		

ANALYSES OF FRESH ELÆOLITE SYENITE AND RESIDUAL KAOLIN.

Constituents	1 Fresh syenite	2 Residual kaolin	3 Loss	4 Percentage amount of each constituent saved	5 Percentage amount of each constituent lost
Silica .....(SiO_2)	59.96	45.81	37.28	37.82	62.18
Alumina .....(Al_2O_3)	18.92	38.19	0.00	100.00	0.00
Ferric Iron ..... (Fe_2O_3)	4.87	1.34	4.19	13.83	86.17
Lime .....(CaO)	1.35	0.33	1.19	12.10	87.90
Magnesia .....(MgO)	0.69	0.25	0.57	17.90	82.10
Potash .....(K_2O)	6.00	0.23	5.90	18.15	81.85
Soda ..... (Na_2O)	6.32	0.37	6.15	2.89	97.11
Ignition.....(H_2O)	1.84	13.48	0.00	100.00	0.00
Total loss.....			55.28		

ANALYSES OF FRESH AND DECOMPOSED DIORITE.

Constituents	1 Fresh diorite	2 Decomposed diorite	3 Loss	4 Percentage amount of each constituent saved	5 Percentage amount of each constituent lost
Silica.....(SiO_2)	46.74	42.45	17.43	62.69	37.31
Alumina.....(Al_2O_3)	17.61	25.51	0.00	100.00	0.00
Iron sesquioxide..(Fe_2O_3)	16.79	19.20	3.53	78.97	21.03
Lime .....(CaO)	9.46	0.37	9.20	2.70	97.30
Magnesia.....(MgO)	5.12	0.21	4.97	2.83	97.17
Potash.....(K_2O)	0.55	0.49	0.21	61.25	38.75
Soda.....(Na_2O)	2.56	0.56	2.17	15.13	84.87
Phosphoric acid ...(P_2O_5)	0.25	0.29	0.05	80.11	19.89
Ignition .....(C and H_2O)	0.92	10.92	0.00 [1]	100.00	0.00
Total loss.....			37.56		

[1] A gain.

ANALYSES OF FRESH LIMESTONE AND ITS RESIDUAL CLAY.

Constituents	1 Fresh limestone	2 Residual clay	3 Loss	4 Percentage amount of each constituent saved	5 Percentage amount of each constituent lost
Silica .....(SiO_2)	4.13	33.69	0.00	100.00	0.00
Alumina ..... (Al_2O_3)	4.19	30.30	0.35	88.65	11.35
Ferric oxide ..... (Fe_2O_3)	2.35	1.99	2.13	10.44	89.56
Manganous oxide ..(MnO)	4.33	14.98	2.49	42.41	57.59
Lime .....(CaO)	44.79	3.91	44.31	1.07	98.93
Magnesia .....(MgO)	0.30	0.26	0.26	10.62	89.38
Potash .....(K_2O)	0.35	0.96	0.23	33.63	66.37
Soda .....(Na_2O)	0.16	0.61	0.085	46.74	53.26
Water ..... (H_2O)	2.26	10.76	0.95	58.37	41.63
Carbonic acid .....(Co_2)	34.10	0.00	34.10	0.00	100.00
Phosphoric acid ...(P_2O_5)	3.04	2.54	2.73	10.24	89.76
Total loss			77.635		

In reference to these analyses, it is advisable to make the following statement:

The Virginia gneiss, in the first table, in its fresh condition, as analyzed, is a coarse, gray feldspar, a rich variety, with abundant folia of black mica.

Under the microscope it shows the presence of both potash

and soda-lime feldspars, a sprinkling of apatite and iron ores, sporadic occurrences of an undetermined zeolite, and an extraordinary number of minute zircons, which are mostly included in the feldspars. The residual soil resulting from its decomposition is highly plastic, of a deep red-brown color and has a distinct gritty feeling owing to the presence of quartz and undecomposed silicates. Some 69 per cent. of this soil was found to be soluble in dilute hydrochloric and sodium carbonate solutions. It will be noted that 44.67 per cent. of the original matter has disappeared, and that of the original silica 52.45 per cent. is lost, while 85.65 per cent. of the iron and all the alumina and phosphoric acid remain. All the lime has disappeared; 83.52 per cent. of the potash, 95.03 per cent. of the soda and 74.70 per cent. of the magnesia are likewise missing. The total amount of water has increased very greatly, as was to be expected. The calculation shows a small apparent gain in phosphoric acid, but the amount of this constituent is so slight in the original rock as to render it probable that this is due to errors of analysis.

The elæolite syenite in the second series is a coarsely crystalline granular rock containing orthoclase feldspar in broadly tabular forms, accompanied by nepheline, biotite, pyroxene, titanite and apatite, while fluorite, analcite, and thomsonite, together with calcite, occur as secondary products. The rock weathers away to a coarse gray gravel which ultimately yields a clay from which may be obtained, by washing, a kaolin of a fair degree of purity. The analyses are from the work of J. Francis Williams.[1]

The calculations show a much greater loss of silica than in the gneiss, a feature due, as will be noted later, to the absence of free quartz in the syenitic rock. Attention should be called to the fact that the soda has been carried away in greater proportions than the potash.

The diorite in the third series of analyses is, when fresh, a compact fine-grained, almost coal-black rock, sometimes finely speckled with white from the presence of feldspars. The micro-

[1] Ann. Rep. State Geol. Survey of Arkansas, 1890, Volume II.

scope shows it to be composed mainly of hornblende and soda-lime feldspars with interstitial areas of titanic iron. The clay or soil to which it gives rise on decomposing is deep brownish-red in color and highly plastic, though distinctly gritty from the presence of undecomposed feldspars. Though so rich in iron it is to be noted that the residual clay is little if any deeper in color than that from the gneiss. The analysis shows that 37.56 per cent. of the total rock has disappeared.

The limestone of the fourth series is of Carboniferous Age, very impure, crystalline granular, and of a dark chocolate-brown color. The residual clay from its decomposition is a trifle darker, highly plastic and quite impervious. The analyses, calculations, and descriptions are from the work of Penrose.[1]

It is to be noted that all that the lime which existed as carbonate, has been entirely removed, as shown by the absence of carbonic its acid in the clay. Farther, that the clay, notwithstanding highly hydrated condition, in reality contains scarcely half the amount of water it would, had the small amount (2.26 per cent.) in the fresh limestone been allowed to accumulate without loss.

DISCUSSION OF RESULTS AND RÉSUMÉ.

Taking now into consideration in connection with these analyses the statements embodied in the first part of this paper relative to the agencies of degeneration, and making due allowance for possible errors in our methods of calculation, there are certain general deductions that may, apparently, be drawn with safety. In the résumé given below, however, reliance is placed not more upon our own analyses than upon results obtained by others as given in existing literature.[2]

Let us briefly review the subject and make the deductions accordingly.

In glancing over the columns of our analyses it is at once

[1] Ann. Rep. Geol., Survey of Arkansas, 1890, Volume I.

[2] See especially Roth's Allegemeine u. Chemische Geologie, Vol. III, and Ebelman's papers in Annales des Mines, Vols. VII, 1845, and XII, 1847.

apparent that hydration is an important factor, the amount of water increasing rapidly, as decomposition advances. There is, moreover, among the siliceous crystalline rocks in every case a loss in silica, a greater proportional loss in lime, magnesia, and the alkalies, and a proportional increase in the amounts of alumina and sometimes of iron oxides, though the apparent gain may in some cases be due to the change in condition from ferrous to ferric oxide. As a whole, however, there is a distinct loss of materials, though the residuary product may actually contain a larger percentage of certain constituents than did the rock from which it was derived.

According to Bischof and as shown in our own work the silicates in any rock that are most readily decomposed are, as a rule, those containing protoxides of iron and manganese, or lime, and the first indication of decomposition is signaled by a ferruginous discoloration and the appearance of calcite.

Fournet, from a study of the processes of kaolinization, was led to state[1] that the hornblende yields less readily to decomposing forces than does feldspar, when the two are associated in the same rock. Becker, however, in studying deep-seated decomposition in the Comstock lode of Nevada, arrived at a precisely opposite conclusion, the feldspars as a whole offering more resistance than the augite, hornblende, or mica.

The present writer has described[2] thick sheets of augite porphyrite in Gallatin county, Montana, in which the feldspathic disintegration has gone on so far that the mass falls away to a coarse sand, from which still perfectly outlined crystals of coal-black augites may be gleaned in profusion. This last is, however, in a semi-arid region, and the process thus far more one of disintegration than decomposition.

In any climate, minerals consisting chiefly of silicates of alumina and magnesia are less liable to decomposition than those containing iron protoxides, or lime carbonates, for the reason that the first named are not easily affected by carbonic acid.

[1] Ann. de Chimie et de Physique, Vol. LV, 1833, p. 240.

[2] Bull. U. S. Geol. Survey, No. 110, 1894.

Indeed it is ordinarily assumed that the silicate of alumina is not at all affected, but the researches of Müller, to which we have referred, seem to disprove this, as do also the calculations made in previous pages. Those silicates which are least liable to atmospheric decomposition are, as it is to be expected, those which have resulted from the alteration of less stable silicates, as serpentine from olivine, epidote from hornblende, or kaolin from feldspar, etc. So much is this so that serpentine has been called a final product of alteration. A few silicates like tourmaline and zircon, or garnet, or oxides like rutile and magnetite, or the salts of rarer earths like monazite, etc., are scarcely at all affected by any of the ordinary products of decomposition, but remain in the form of residual sands in the beds of streams, from whence the lighter, more decomposed, material is removed by erosion.

In the weathering of potash feldspar rocks carrying black mica, the latter mineral is, as a rule, the first to give way, and at times almost wholly disappears. With basic rocks, on the other hand, the dark mica is one of the most enduring of the constituents, and in the residual sands may be found in surprisingly large proportions.

Among the feldspars the potash varieties are, as a rule, far more refractory than the soda lime, or plagioclase, varieties. This is shown not merely by our own investigations, but by those of others as well. Roth shows[1] from analyses of fresh and weathered phonolites, nepheline basalts, and dolorites that the loss of soda is almost invariably greater than that of potash.

Indeed as shown in our analyses the potash feldspars may lose very little by decomposition, but be converted into the condition of fine silt merely through a mechanical splitting up. This fact will in part explain the relative scarcity of free potassium salts (carbonates, sulphates, and nitrates) as compared with those of soda.[2]

[1] Op. cit., 3d ed., 2d Heft.

[2] An oligoclase occurring in a tourmaline granite on the southern slope of Mt. Mulatto, near Predazzo, undergoes, according to Lemberg (Zeit. der deutsch. geol. Gesellschaft, 28, 1876), a much more rapid decomposition than the orthoclase with which it is associated, and gives rise to a green lusterless serpentine-like product. The

The chemical processes involved in this feldspathic decomposition are of sufficient importance to warrant further discussion, even though it may involve a certain amount of repetition of what has gone before.

Berthier, Forschammer, Brogniart,[1] Fournet,[2] and others explained more than fifty years ago the process of feldspathic disintegration through the breaking up of its complex molecule into alkaline silicates soluble in water and aluminous silicates which are insoluble. The loss in silica, as noted above, was supposed to be due to the removal, by solution, of these alkaline silicates. Ebelman,[3] however, subsequently showed that silicate minerals poor or quite lacking in alkalies lost a portion of their silica with equal facility. He accounted for this on the supposition that the silica set free—in a nascent state—was soluble either in pure water, or water containing carbonic acid. Bischof states that when meteoric waters containing carbonic acid filter through rocks containing alkaline silicates, the first action consists in the partial decomposition of these substances by the carbonic acid, and the formation of alkaline carbonates, which are dissolved.

If the water thus impregnated, on penetrating further below the surface, comes in contact with calcareous silicates, another change will take place consisting of a decomposition and replacement of these calcareous silicates by the alkaline silicates, and a

chemical changes incidental to the alteration are as shown in the following tables, I being the fresh oligoclase and II the decomposition product.

	I.	II.
Silica,	59.51	45.29
Alumina,	25.10	25.68
Iron sesquioxide,	1.08	12.29
Lime,	4.03	0.52
Magnesia,	trace	2.98
Potash,	2.10	3.00
Soda,	7.26	2.14
Water,	0.92	12.49

[1] Arch du Museum, Vol. I, 1839 (cited by Ebelman).

[2] Annales de Chimieet de Physique, Vol LV, 1833.

[3] Annales des Mines, Vol. VII, 1845.

removal of the lime set free, as a carbonate, provided the water still contains a sufficient amount of carbonic acid. This replacing process and the retention of the alkaline silicates is accounted for on the supposition that, in their nascent state, they form new combinations with the other silicates present, while the lime remains as a carbonate to be removed or not as the case may be. He further states that the alkaline carbonates originating in the manner described are among the most soluble substances known; the carbonate of soda requiring for solution only six times its weight of water at ordinary temperatures. Silica, on the other hand, even in its most soluble form, requires 10,000 times its weight of water for solution. If, therefore, the decomposition of feldspar by such carbonated water were ever so energetic, there would be sufficient water for the solution of the carbonate of soda formed. But if the silica separated meanwhile amounted to more than $\frac{1}{10000}$ of the water present, the excess could not be dissolved, but would remain mixed with the kaolin.

The case is very different when the decomposition of feldspar is effected by fresh water containing only minute quantities of carbonic acid. By the action of such water, only very small quantities of alkaline carbonates are formed; consequently it is possible that the silica separated at the same time, also small in quantity, may find enough water for solution. In such cases the whole of this silica would be removed with the alkaline carbonates, and pure kaolin would be left. Such an action as this does not appear to take place; for the purest of kaolin nearly always contains an admixture of quartz sand or of free silica in some of its forms.

H. P. Murakozy[1] has shown that in the decomposition of rhyolite from Nagy-Mihely, the sanidin passes into kaolin and opal, the latter separating out as hyalite in veins or impure concretionary forms. Through this abstraction of silica there is an apparent proportional increase in the amounts of alumina and alkalies.

It follows from the above considerations that in the decomposition of feldspar into kaolin, more of the silica separated remains

[1] Abstract of F. Becke, Neues Jahrbuch, 1894, 1 Band, 2 Heft, p. 291.

mixed with the kaolin formed, the greater the quantity of carbonic acid in water, and that, perhaps, the amount of carbonic acid in water is never so small that the whole of the silica separated in the decomposition of feldspar can be removed.[1] The above, however, wholly overlooks the possible presence of nitrates, such as we now know from the researches noted on p. 857 must in many cases exist even though in extremely small proportions. It is probable that the small amounts of nitric acid formed by the bacteria would, if not at once taken up by plants, combine immediately with the alkalies, potash, or soda, forming nitrates which, owing to their ready solubility, would be carried away. The larger the proportion of nitric acid, therefore, the greater would be the amount of carbonic left, and consequently the greater would be the amount of silica intermingled with the kaolin, since whatever proportion of the alkalies failed to be carried away as nitrates would pretty certainly disappear as a carbonate. There is also the possibility, especially in the rocks rich in iron protoxides, that a portion of the silica may combine with the iron. (See Bischof, Vol. II, p. 77.)

In cases where the decomposition takes place under the influence of a sufficient supply of oxygen, all iron and presumably the manganese as well would be converted into the insoluble hydrous sesquioxide form and remain with the residue. Where, however, the supply of oxygen is insufficient, a portion or all of these constituents may be removed in the form of protoxide carbonates, or, in the case of iron, as a sulphate.

Reference has already been made to the fact that the magnesia from the decomposition of magnesian silicates was sometimes removed in greater relative portions than was the lime. This seeming anomaly is also sometimes met with in calcareous stratified rocks.

Roth[2] states that in the weathering of dolomitic limestones the magnesia is often removed in greater proportional quantities than the more soluble lime carbonate.

[1] Chemical and Physical Geology, Gustav Bischof, Vol II, pp. 182, 183.

[2] Op. cit., Vol. III.

The researches of Hitterman[1] show, however, that carbonic acid solutions *may* exert a scarcely appreciable effect upon magnesian carbonates, which therefore accumulate in the residual soils. In residues derived from limestones this authority also found percentages of alkalies greatly in excess of those in the unchanged rock, indicating beyond a doubt the occurrence of these constituents in the form of insoluble silicates.

It is safe to say that while the general process of rock-weathering may be quite simple, as outlined, there are many minor reactions which it is not possible to describe in detail. It has been shown that even in firm rocks a mutual chemical reaction is not uncommon among minerals lying in close juxtaposition, giving rise to what are known as reaction rims or zones composed of secondary minerals. This is a particularly conspicuous feature in many gabbros where olivine and feldspar are closely adjacent. In these cases a mutual interchange of elements may take place, giving rise to garnets, free quartz or other minerals, as the case may be. This is, to be sure, a deep-seated change, to be classed as alteration rather than decomposition, and taking place presumably under conditions of temperature and solution quite at variance with those existing on the immediate surface. It is, nevertheless, self-evident that when elements are set free through any process, they must almost immediately recombine, taking those forms which existing circumstances may dictate. In a mass of decomposing rock circumstances are almost continually changing, and the inference is fair that new combinations are continually being made and unmade, the intricacies of which we are unable to follow.

Among the siliceous crystalline rocks superficial disintegration is undoubtedly greatly aided by temperature variations which, by rendering the rocks porous, facilitate chemical decomposition. Such action must, however, be merely superficial, and at considerable depths below the surface the change must be purely chemical. The chief conditions favoring chemical action

[1] Die verwitterunge Producte von Gesteinen der Triasformation Franken. Inaug. Dissertation. Munich, 1889.

are those of continual percolation by waters carrying the organic acids already described. It naturally follows therefore that a purely chemical decay will progress more rapidly where the rock-mass is covered by such a layer of vegetable soil as shall give rise to the decomposing solutions. Hence, that such an accumulation having begun decomposition will keep on at an ever increasing rate to a depth concerning which we have at present no data for calculation. It must not be too hastily assumed from this that rocks thus protected do in reality disintegrate more rapidly than those exposed on bare hillsides, since here, where physical causes predominate, the loosened particles are removed as fast as formed, and, besides leaving no measure of the destruction going steadily on, new surfaces for attack are being continually exposed. Moreover, in assuming that rocks decay rapidly where covered by vegetation we must not overlook the fact that the character of the overlying soil may be such as to be protective rather than otherwise. Thus, in glaciated regions it is a well-known fact that the striæ on rock surfaces are found best preserved where they have been protected from heat and frost by a mantle of drift, or the compact turf so characteristic of the northern states.

The principles involved in the decomposition of fragmental and stratified rocks are not so different from those we have been discussing as to call for detailed consideration. It is well to note, however, that the materials composing rocks of this type are themselves a product of these very disintegrating and decomposing agencies, but which have become consolidated into rock-masses, and now, once more in the infinite cycle of change, are undergoing a breaking up. It follows from the very nature of the case that such rocks, with the exception of the purely calcareous varieties, will undergo less chemical change than do those we have been discussing. Their feldspathic and easily decomposable silicate constituents long ago yielded to the decomposing processes, and were largely or in part removed before consolidation took place. Thus most sandstones are composed largely of quartzose sand, the least soluble and least changeable product, it

may be, of many a previous disintegration. Hence, the processes involved in the disintegration of the sandstones, shales and argillites are mainly mechanical, with the exception of those which carry a feldspathic or calcareous cement.

It is, however, quite different with the calcareous members of the group, where, with the exception of the granular-crystalline varieties, the process is almost wholly chemical, and notable for its simplicity. In these latter forms, as the saccharoidal marbles, expansion and contraction, from ordinary temperature variations, bring about a more or less rapid disintegration. The decomposition is, however, due mainly to the action of meteoric waters trickling over the surface, or filtering through cracks and crevices under ordinary conditions of atmospheric pressure and atmospheric temperature. Hence, the process is one of superficial solution, and the incidental chemical processes set in motion, as in the feldspar-bearing rocks, are almost entirely lacking. It follows that only the lime carbonate is removed in appreciable quantities, while the less soluble impurities are left to accumulate in the form of ferruginous clays, admixed with quartzose particles, chert nodules, etc. Since in many limestones the amount of these constituents is reduced to a minimum, even, perhaps, to the fraction of 1 per cent., so it happens that hundreds or even thousands of feet of strata may be removed without leaving more than a very thin coating of soil in its place.

GEORGE P. MERRILL.

Editorial.

In the American chapter of the third edition of Dr. Geikie's *Great Ice Age*, formational names were proposed for three of the better known till sheets of the glacial series. It was not without some hesitation that this was done because it was not wholly clear that the time was ripe for nomenclature, but the helpfulness of specific names and the superiority of stratigraphic terms over the time-phrases, period, epoch and episode, of controverted application, seemed to overbalance the infelicities that would arise from the immature state of investigation. It was anticipated that further study would give occasion for additions and emendations. The ready and general acceptance of the names seems to have justified their proposal; indeed, other workers in the glacial field have felt that the method might, even at once, be extended to other divisions less well elaborated. To the names Kansan, Iowan and Wisconsin, which were suggested for the three best known till sheets (Toronto being applied to an interglacial fossiliferous deposit, and Aftonian being subsequently added) Dr. George M. Dawson has proposed to add the term Albertan to designate a series older than the Kansan, and Mr. Upham has proposed the addition of Warren, Iroquois and St. Lawrence to designate later till sheets. Previous to these additions Dr. Geikie had proposed a full series of similar names for the European glacial deposits.

The studies of the past two years seem to show that within the limits of the series covered by the three names first proposed, there is, probably, need for some extension and revision. This arises chiefly from the progress made by the geologists of the Iowa Survey, Messrs. Calvin, Bain, Norton and Beyer, and by my colleague, Mr. Leverett. It will be recalled that in eastern Iowa

the elaborate investigations of Mr. McGee some years ago demonstrated the existence of two sheets of till, separated by a vegetal horizon. It was known that in southern Iowa there were also two sheets of till separated by a vegetal horizon, but these had not been studied in detail nor their connections traced out. It was natural, as well as prudentially conservative, to suppose that these two series were mutual equivalents, as they stood in much the same geographic relationship to the later (Wisconsin) drift. It was recognized that the amount of erosion upon the south Iowan series was greater than that upon the east Iowan, and also that the loess in eastern Iowa was intimately connected with the upper till sheet, while the upper till sheet in southern Iowa was separated from the loess by a definite interval, but the importance of these differences was not fully appreciated. The investigations of the Iowa geologists have led to the quite firm conviction that the upper till sheet of the series in southern Iowa is the lower member in eastern Iowa. They have also become convinced that the upper sheet in southern Iowa extends continuously across northwestern Missouri into Kansas, and is the equivalent of the drift sheet that covers the northeastern part of Kansas. State Geologist Keyes of Missouri concurs in this view. They do not hold this to the exclusion of a possible lower member in Kansas. In harmony with these views the upper till in the southern part of Iowa has been designated Kansan in the recent Iowa reports.

During the past summer I have had the pleasure of making two excursions with Mr. Bain of the Iowa survey to localities where the above formations are advantageously exhibited, and I have been impressed with the cogency of the arguments of the Iowa geologists. While, therefore, the case cannot be said to be demonstrative, as yet, it seems best to accept the application of the nomenclature adopted by the Iowa survey. This places the Aftonian beds below the Kansan series instead of above them. It puts the sub-Aftonian sheet of till in an earlier category, and, for the present, it may perhaps be regarded tentatively as Albertan, although, of course, it cannot now be

demonstrated to be equivalent to the Albertan beds of Canada. The studies of Mr. Leverett have made it quite sure that the Kansan ice-sheet crossed the Mississippi and invaded Illinois to some moderate distance. He has also shown that the Illinois ice-sheet returned the compliment and invaded Iowa. Between these invasions there was a considerable interval of time, as indicated by the greater erosion of the Kansan deposits and by the prevalence of a soil horizon and of peat beds between the Kansan and Illinois till sheets where they overlap. He has shown also that there was a notable interval between the invasion of Iowa by the Illinois ice-sheet and the spreading of the loess over its deposits, as indicated by erosion and the formation of a soil horizon. This loess mantle seems to be identical with that which is intimately connected with the east Iowan drift sheet. It thus appears that the invasion of the Illinois ice marks a distinguishable stage of glaciation separated by a notable interval from both the earlier Kansan stage and the later Iowan stage. This interval appears to be of such moment as to make it inadvisable to correlate the Illinois drift sheet with the Iowan drift sheet. As a result, the practice of designating the former the Illinois sheet has already sprung up among us. The evidence at present seems sufficient to justify its tentative use in the literature of the subject. It should of course be credited to Mr. Leverett.

The series in the Mississippi basin, as thus modified, would be as follows in stratigraphic order:

9. Wisconsin Till Sheets (earlier and later).
   8. Interglacial deposits (Toronto perhaps).
7. Iowan Till Sheet.
   6. Interglacial deposit.
5. Illinois Till Sheet (Leverett).
   4. Interglacial deposit (Buchanan of Calvin).
3. Kansan Till Sheet.
   2. Aftonian beds, Interglacial.
1. Albertan Drift Sheet (Dawson).

The completion of the nomenclature by the naming of the interglacial deposits is desirable, but it is doubtful whether it can be satisfactorily done at present. The correlation of the Toronto beds with the Mississippi series seems to me to remain uncertain, but they are so preëminently fitted to give name to their horizon that it seems best to reserve for them the place to which they most probably belong. Some of the known vegetal deposits found below the Iowan till sheet could appropriately give name to the interglacial deposits between the Iowa and Illinois beds if their horizon could be positively fixed, but it cannot now be stated certainly whether the interval marked by these is that between the Iowan and Illinois sheets, or that between the Illinois and Kansan sheets. The Buchanan gravels are regarded by Professor Calvin as marking the initial stages of the interval following the formation of the Kansan drift, and the term Buchanan has been employed by him in designating this interval. The probable close connection between the formation of these gravels and the underlying drift renders the name something less than ideal as the designation of true interglacial deposition, but the pronounced characteristics of the formation and its great significance, joined to its excellent exposure and easy accessibility, make it doubtless the best nominative deposit now available.

While returning from my last visit to the field in which the Kansan, Illinoian, Iowan, and Wisconsin formations were seen in close succession, I made a memorandum of impressions respecting their relative ages simply as a means of comparison with judgments formed at other times, the impressions being derived from the respective degrees of erosion and chemical change which the formations have undergone. Although this was intended to be nothing more than a record of passing impressions, it may be the best means of giving some notion of my rating of the historical importance of the formations. Taking the interval from the late Wisconsin deposits (as found immediately south of the Great Lakes) to the present date as unity, the following is the memorandum:

From the close of the later Wisconsin to the present,	1	unit
From the earliest Wisconsin (Shelbyville moraine) to the present,	2½	units
From the Iowan to the present,	5	"
From the Illinois invasion of Iowa to the present,	8	"
From the Kansan to the present,	15	"
From the sub-Aftonian (Albertan) to the present,	*x*	"

Four of the investigators previously named who have seen this memorandum are disposed to increase the figure for the Kansan, and some of them would alter other figures in the same direction, with perhaps a reduction of the estimate for the Iowan. After the estimate had been made it was observed that the intervals form a symmetrical diminishing series. The temperature variations of the period might therefore be represented by an oscillating curve with declining waves.

T. C. C.

Reviews and Abstracts.

Physical Features of Missouri. By Curtis Fletcher Marbut. *Geological Survey of Missouri*, Vol. X, pp. 1–109, 1896.

This report represents one of the first attempts on the part of a state geological survey to interpret the physical geography of the state concerned from the modern standpoint. The report brings out many interesting facts and relations, even though the topographic map of the state is not complete, and all the data which the area may ultimately afford for the interpretation of its geography are therefore not now available.

The general physical features of the state are discussed from the standpoint of history. The processes of their evolution, and their dependence on geological structure are emphasized, thus bringing out what geographers have long recognized—that any rational interpretation of geography must be based upon a knowledge of geological structure.

The general physiographic provinces of the state are outlined, and their leading characteristics succinctly set forth, and set forth in such a way as to give them a meaning. It is not too much to say that any one who masters this part of Mr. Marbut's report will have a conception of many of the common processes by which topography is developed, and will have acquired some ability to interpret geography for himself.

In the discussion of the hydrography of the state, the same fundamental principles of treatment are followed. Various types of drainage, as drainage is now classified, are found to exist within the state, and specific illustrations are pointed out. It is one of the evidences of the right methods of river study now in vogue, that they are found to fit regions which had not been studied when they were adopted. Many special features of valleys as developed in Missouri are discussed, and new illustrations of various well-known principles are furnished. River meanders come in for special and discriminating discussion.

One of the chief objects to be attained by the systematic treatment of physical geography by the state surveys is educational. It is in every way desirable to disseminate accurate information among the people, and to have the information in such form that it will stimulate independent study. Another object is to furnish professional geographers with accurate knowledge of the region studied. Mr. Marbut's report must be looked upon as more successful from the standpoint of geographers, than from the standpoint of those who are not. Judged from the standpoint of the reader who is not posted in the principles and nomenclature of modern geography, the report is in danger of seeming unnecessarily technical and so of not being understood. This danger is enhanced by the fact that it occasionally lacks in clearness, both because the language is obscure, and because of the lack, at some points, of adequate illustration. Another defect in the same line appears in the frequent references to places which no accompanying map locates. From the standpoint of the geographer these defects may not be serious, but from the standpoint of the citizen who is not a geographer, it is to be feared that they will too often cause the report to remain unread. It goes without saying that it is much easier to point out these shortcomings than to remedy them.

A question is here raised, by way of suggestion, rather than of criticism, concerning one of the statements of the report. On page 76 it is said that the upper Mississippi probably assumed its present location in late Cretaceous time. There is some reason, though at present by no means conclusive, for suspecting that the present location of this stream was selected at a much later date, possibly as late as the Tertiary.[1] If it shall prove to be true that the isolated remnants of preglacial gravels, occurring at high levels at various points in the Mississippi basin are Tertiary, the development of the present physiographic features of the Mississippi basin, including the valley of the master stream, must date from a still later time. R. D. S.

Geologic Atlas of the United States. Folio 18, Smartsville, California, 1895.

This folio consists of four pages of text, signed by Waldemar Lindgren and H. W. Turner, geologists, and G. F. Becker, geologist in charge; a topographic sheet (scale 1:125,000), a sheet of areal geology, one of economic geology, and one of structure sections.

Topography.—The district of country represented lies between the

meridians 120° and 121° 30′ and the parallels 39° and 39° 30′, and embraces about 925 square miles, comprising a part of the foothill region of the Sierra Nevada. The elevation ranges from 50 feet above sea level in the northwestern corner to over 4000 feet in the northeastern corner. The topography is characterized by a number of parallel ridges, running in a north-northwest direction. The northeastern part has more the character of an irregular and undulating table-land. Through the ridges and the plateaus the watercourses have cut deep and narrow canyons. The Yuba River, with its branches, drains the larger part of the district. Honcut Creek on the north and Bear River on the south, are the only other streams of importance.

Geology.—Sedimentary formations occupy comparatively few areas in the district, all of which has been tentatively referred to the Calaveras formation, no fossils having been found in them. They consist of slates and quartzitic sandstones, usually with northerly strike and steep easterly dip. Diabase and porphyrite occupy large areas in the central and southern parts, as well as intrusive masses of granodiorite and gabbrodiorite. Amphibolites, resulting from the dynamo-metamorphism of diabase, gabbro, and diorite, also occur in several places. The rocks of the district are principally massive, in contrast to those of the districts adjoining on the south and east. However, two lines traverse it along which extensive metamorphism has taken place and schistose rocks have been developed. The superjacent rocks, resting unconformably on the older series, consist of Neocene river gravels together with beds of andesitic and rhyolitic tuffs. Comparatively small areas of these remain, the larger part having been carried away by erosion. Pleistocene shore gravels and alluvium occupy the southwestern corner. The Ione formation is not well exposed in this district, being in part covered by Pleistocene deposits, in part removed by erosion.

Economic Geology.—Important and rich Neocene gravel deposits in this district have been worked at Camptonville, Nevada City, North San Juan, Badger Hill, French Corral, and Smartsville. Gold-quartz veins occur scattered throughout the area, but by far the most of them are found in the immediate vicinity of Nevada City and Grass Valley. These districts are among the most important of the gold-mining regions in California. Many of the rocks of the district are adapted for building purposes. The only one in extensive use is the granodiorite near Nevada City. The often deep red soils in the foothill region are of

residuary origin. Extensive areas of alluvial and sedimentary soils are found only in the southwestern corner.

Sixteenth Annual Report, U. S. Geol. Survey, CHARLES D. WALCOTT, Director. Washington, 1896.

The report is issued in four volumes of which the first embraces the administrative reports and all papers of a theoretic nature. Among the latter are: "The Dinosaurs of North America," by O. C. Marsh; "Glacier Bay and its Glaciers," by H. F. Reid; "Some Analogies in the Lower Cretaceous of Europe and America," by L. F. Ward; "Structural Details in the Green Mountain Region in Eastern New York," by T. N. Dale; "Principles of North American Pre-Cambrian Geology," by C. R. Van Hise; "Summary of the Primary Triangulation Executed Between 1882 and 1894," by Henry Gannett. In part second, made up of papers of an economic character, are, among others, "Reports upon Cripple Creek," by Cross and Penrose, "A Reconnoissance across Idaho," by G. H. Eldridge, "A Report upon the Mercur Mining District," by J. E. Spurr, and a paper upon "The Public Lands and their Water Supply," by F. H. Newell. Parts three and four contain the matter formerly published separately in the series of volumes known as *Mineral Resources*.

Additional reviews and abstracts crowded out of this number will appear in the following issue.